MONTHLY NOTICES

OF THE

ROYAL ASTRONOMICAL SOCIETY

CONTAINING

PAPERS, ABSTRACTS OF PAPERS, AND REPORTS
OF THE PROCEEDINGS OF THE SOCIETY

VOL. 102

Published and Sold by the
ROYAL ASTRONOMICAL SOCIETY
BURLINGTON HOUSE
LONDON, W. 1

1942

Printed in Great Britain by
Neill & Co., Ltd., Edinburgh

MONTHLY NOTICES

OF THE

ROYAL ASTRONOMICAL SOCIETY

Vol. 102 No. 1

MEETING OF 1942 MARCH 13

Professor S. Chapman, President, in the Chair

The election by the Council of the following Fellow was duly confirmed:—

James Fielding, Sunnyhurst, Ffriddoed Road, Bangor, Caernarvonshire.

The following candidates were proposed for election as Fellows of the Society, the names of the proposers from personal knowledge being appended:—

Charles Edward Rhodes Bruce, M.A., B.Sc., British Electrical and Allied Industries Research Association, 15 Savoy Street, London, W.C. 2 (proposed by E. T. Whittaker);

Mark Howarth, Grange Mount Observatory, Mayfield, Newcastle, N.S.W., Australia (proposed by W. F. Gale); and

Captain Leonard F. Plugge, M.P., 5 Hamilton Place, Piccadilly, London, W. 1 (proposed by S. Chapman).

One hundred and forty-two presents were announced as having been received since the last meeting, including:—

F. Seares, F. E. Ross and M. C. Joyner, Magnitudes and Colors of Stars North of +80° (presented by the Carnegie Institution of Washington); and

W. M. Smart, Foundations of Astronomy (presented by Messrs. Longmans, Green & Co. Ltd.).

The President referred to the death of Dr. H. D. Curtis, an Associate of the Society, and paid the following tribute (the Fellows standing):—

"Fellows will have heard with regret of the death, on January 8, of our Associate Dr. Heber D. Curtis, Director of the Observatories of the University of Michigan. He was widely known for his work on the external galaxies and on stellar spectroscopy, and also as a veteran eclipse observer (he observed eleven). Before 1930 he was Director of the Allegheny Observatory. Many Fellows will well remember his last visit to the Society, in 1938 November, and the remarkable solar prominence films which he showed us, taken at the McMath-Hulbert Observatory."

A Discussion was held on Solar Eruptions (following on papers read by Messrs. Newton and Ellison), and Professor Duperier gave a short account of the work he is doing on Cosmic Rays.

CHARACTERISTIC RADIAL MOTIONS OF *Hα* ABSORPTION MARKINGS SEEN WITH BRIGHT ERUPTIONS ON THE SUN'S DISC

H. W. Newton

(Communicated by the Astronomer Royal)

(Received 1942 January 28)

1. One of the chief uses of the spectrohelioscope is to locate short-lived phenomena on the Sun's disc. Notable among these are the bright chromospheric eruptions which have been linked up with certain ionospheric disturbances. Whilst attention has been concentrated on the flares themselves—their sudden origin, brightness and other features —it has been difficult for the observer to follow in any detail the life-history of transient absorption markings which often appear in close association. In the spectrohelioscope observations made at Greenwich, absorption markings have been observed in association with about 80 per cent. of the brightest eruptions (intensity = 3); for bright eruptions of intensity = 2, the observed association was 70 per cent., and for those of smallest intensity (= 1) 50 per cent. These are minimum values, because, to give one reason, whilst bright flares are nearly always best seen in the middle of *Hα*, indicating the absence of Doppler shifts, the observer must "hunt" with the line-shifter for the presence of absorption markings with medium or large radial velocities. If photometer measures are being made on the bright emission itself, only infrequent scouting with the line-shifter is possible.

In *M.N.*, **95**, 650, 1935, attention was drawn to the occurrence of outward velocities followed by inward velocities, which seemed to characterize dark markings found in close association with bright eruptions. These absorption markings evidently represent prominences (in many cases, rising and falling in nearly the same place) seen in plan on the Sun's disc. In the simplest cases, the plan picture appears as a small blob 10″ to 30″ in diameter; in others, as a short dark streak, curved or straight. The observer then feels some confidence that he is following the same mass of absorbing *Hα*, or at least related masses from the same point of origin in the chromosphere. Direct measures of the components of radial velocity of prominences seen thus in plan are obviously a valuable addition to the time-height measures made at the Sun's limb.

The collecting of satisfactory disc data has, however, been slow, owing to the rapidity of the phenomena and to the priority given to observations of the initial bright eruptions, for which data were primarily sought on account of the associated ionospheric effects brought to light by observations at Greenwich and elsewhere in 1935–38. Although it was hoped to collect fuller data than has been possible at Greenwich up to the present, certain features have emerged which seem worth stating now for guidance in planning future observations with the spectrohelioscope.

It may be noted that if the phenomena described in this paper were recorded by cinematography and projected with the usual time-scale compression of recent prominence films of 1/600, they would go through their life-history on the screen within 2 or 3 seconds.

2. *Instrument and Observing Methods.*—The essentials to be given here are :—

(*a*) The Hale spectrohelioscope * lent to Greenwich in 1929 by the Mount Wilson Observatory is used with a Rowland grating ruled with 14,438 lines to the inch. The width of the selecting slit generally used is 0·10 mm., which in the first order spectrum at *Hα* would include a range of 0·44 A., equivalent to a Doppler-shift range of 20 km./sec.

* *Ap. J.*, 70, 265, 1929.

(*b*) To make a radial velocity measure of a dark *Hα* marking, the line-shifter is turned until the marking appears at maximum density. The line-shifter reading converted into angstroms or km./sec. is differenced from the zero reading, similarly converted, which corresponds to the centre, or bottom of the contour, of the *Hα* line. An alternative method, sometimes used, is to take the line-shifter readings when the chromospheric marking just comes into visibility on each side of its maximum intensity position. The mean of these two readings converted into km./sec. and differenced from the zero value gives the required measure. The Greenwich measures of quiescent dark markings give the average total range of visibility as 1·2 A. For several markings with a mean component of radial velocity of 44 km./sec. the measured range was 1·8 A. In one case included in this paper the range was 4·5 A., the mean Doppler displacement being equivalent to −100 km./sec.

(*c*) The probable error of a single radial velocity measure made on the average quiescent marking is about 3 km./sec. including the p.e. of the zero determination. In the case of large and rapidly changing velocities such as are included in this paper, the probable error must be larger, probably about 5 km./sec.

3. *Data.*—Between 1936 March and 1939 August, sets of measures were made on 25 absorption markings associated with chromospheric patches of abnormal enhancement near sunspots. Nineteen of these bright patches were classified as bright eruptions, nine being of intensity 1, eight of intensity 2 and two of major intensity 3. In the six other cases, the enhanced emission was not quite bright enough nor quite typical in light fluctuation to be classified as a bright eruption. These cases are designated as of intensity < 1.

Identification of the above 25 *Hα* absorption markings may be made by referring to the *Greenwich Photoheliographic Results* for the years 1936–39, in which are or will be published the range of measured radial velocity, data of the associated sunspot, etc. For 1936 the reference numbers are (*loc. cit.*, p. 153) : 46, 96, 100, 109 *, 122, 125, 175, 200, 252. More recent Greenwich *Results* have not yet been published, but identification will be possible later with the help of the following dates :—

1937. Jan 7: Oct. 2. (For 109 * above, refer also to 1937.)
1938. Mar. 15, 18: Apr. 12, 13: May 6, 8: June 10: Sept. 23: Nov. 11, 12.
1939. Mar. 24: May 4: June 29: Aug. 18.

4. *Characteristics of a Recognized Type.*—Of the 25 absorption markings, the life-histories of six were incompletely observed, but their partial evidence is useful. Of the remaining 19, twelve show a distinct similarity in their time-velocity graphs, and their characteristics are presented in fig. 1. This diagram gives, in point of fact, the mean numerical values obtained from the collective observations. The average duration of the associated bright eruptions is indicated by the thick horizontal line at zero velocity.

The distribution curve of measured radial velocities of bright flocculi in general corresponds essentially to that of a probable error of 2 km./sec. Velocities exceeding 10 km./sec. are rare and tend to be found near the Sun's limb.

The life-history of the associated absorption marking falls into three phases.

Phase I: The marking is usually discovered within two or three minutes of the first appearance of the bright eruption. The average measured radial velocity is of the order −50 km./sec., *i.e.* outwards from the Sun, and is caught on a very rapid rise in the measured velocity to a peak value exceeding −100 km./sec. or even −200 km./sec. This peak is near in time to the intensity peak of the bright emission. A rapid decline in outward velocity at once follows, half the peak value being measured within the next two or three minutes.

Then for several minutes (Phase II) the measured outward velocity continues to fall towards zero, usually with a mean retardation less than that due to solar gravity ($2{\cdot}74 \times 10^4$ cm. sec.$^{-2}$). But the absorbing *Hα* cloud is not apparently visible

at the top of its trajectory, for the dark blob which had become dense in appearance now begins to fade rapidly and is usually lost to view at a measured velocity of about −30 km./sec.*

About two minutes before this disappearance occurs, a second dark marking (Phase III), often very close in position to the first, is faintly discernible with a measured component of radial velocity of about 35 km./sec. *inwards* to the chromosphere. At this stage, by oscillating the line-shifter, the pair of markings with − and + velocities

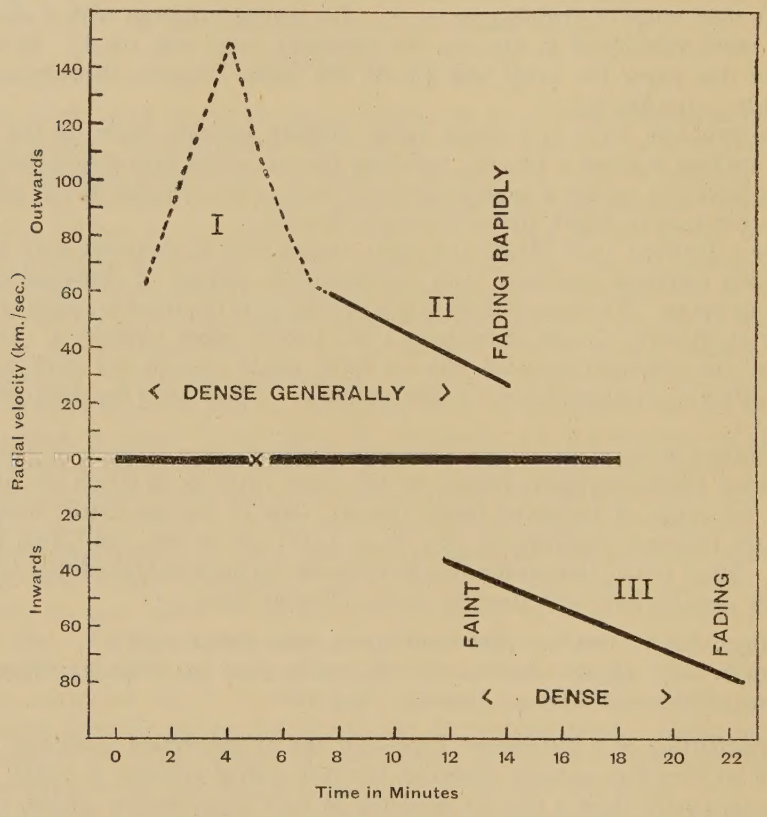

FIG. 1.—*Schematic Time-Velocity Diagram. Type of dark Hα from bright eruptions.*

respectively can usually be seen in close juxtaposition. The new marking gains rapidly in density, and for more than 10 minutes its velocity increases with an approximately constant acceleration less than that due to solar gravity. The marking beginning to fade is soon lost to view at a velocity generally exceeding 50 km./sec. and tending to larger values if the peak outward velocity of Phase I is large.

Of the above phases, the first is the most difficult to observe owing to its sudden onset and the rapidity of its changes. In several cases the peak has been missed altogether; one or two cases do in fact suggest that no marked peak ever occurred. The ending of Phase II and the whole of Phase III are much better observed, for the changes are less rapid and the observer is concentrating on a recognizable sequence of events.

* This velocity, like others given in this section, refers to the centre of maximum density of the marking. From § 2, paragraph (*a*), it follows that the setting of the line-shifter indicating 30 km./sec. may well include velocities from zero to 60 km./sec. A line-contour of an *Hα* absorption marking is given in *M.N.*, **97**, 535, 1937.

The chief details are given in Table I (pp. 6–7) of the observation of each of the twelve dark *Hα* markings with a typical life-history represented in fig. 1. No corrections to the observed radial velocities have been made on account of angular distances of the eruptions from the central meridian. In this preliminary survey the data are sufficient only to find out the broad features of the phenomena. Moreover, the application of a secant correction appears in practice to be of doubtful validity as applied to chromospheric phenomena in general.

The headings of the table are mostly self-explanatory. In column 8, the blanks indicate that the peak was not observed. The addition of brackets indicates that the peak was not fully observed. The 15th column gives the mean deviation of the observed velocities from a straight line, the number of points being given in brackets.

5. *Remarks on the Results.*—Phases I and II: The initial accelerating velocity outwards of absorbing *Hα* within a short time of the origin of the bright eruption strongly suggests some effect of radiation pressure such as has been investigated by E. A. Milne. The observations do not determine whether (*a*) the identical mass of gas is traceable throughout Phases I and II, or (*b*) the sharp drop from the observed maximum velocity indicates a few successive ejections of decreasing initial velocity. If (*a*), then some cause of rapid retardation appreciably greater than that due to solar gravity must operate. There is, however, no corroboration of this in the time-velocity graph of the descending *Hα* of Phase III, which occurs close in time and place to that of Phase I. An alternative explanation to (*b*) is that the gas cloud of the initial ejection (having ascended to greater heights where it becomes invisible to the observer, or having left the Sun altogether) has produced an upward drag on the surrounding chromospheric gases. This secondary effect, if it exists, may be represented by the sudden drop in observed velocities.

Whatever the exact nature of the uprush represented by Phase I, Phase II appears to indicate absorbing *Hα* rising towards the top of its visible trajectory. The mean retardation has now become less than that due to solar gravity, suggesting that there is a radiation-pressure effect from the now diminishing bright eruption or from the general field of normal bright flocculi. The explanation of the disappearance of the dark *Hα* before reaching zero velocity at the top of its trajectory may be connected with diffusion of the cloud or the degree of ionization. The mean order of height deduced in the last column of Table I is 50,000 km.

Phase III presents three interesting features. (1) The appearance of dark *Hα*, not near zero velocity but at 30–40 km./sec. inwards to the chromosphere, the mean value being 36 ± 2 km./sec.; (2) the discontinuity with the outward time-velocity curve, indicating at first sight that a different cloud mass from that of Phases I and II is involved; (3) the average acceleration downwards, ranging from zero to $1{\cdot}9 \times 10^4$ cm. sec.^{2}, is definitely less than that due to solar gravity, suggesting also in this case the operation of radiation pressure.

It will be seen that the time-velocity graph for Phase III produced backwards to zero velocity intersects the time axis near in time to the initial ejection of the dark *Hα*. This in itself suggests that with this initial ejection a downward flow of chromospheric gas begins in a closely adjacent position, similar perhaps to the downward movement of "coronal prominences" as seen at the Sun's limb. But if this be the case, what becomes of the outward moving *Hα* of Phase II, and of Phase I if the latter is not shot outwards into space?

The attention of observers is drawn to this very interesting type of absorption marking found associated with bright *Hα*.* Much fuller data are needed, and the characteristics summarized in fig. 1 may have to be modified in detail. Velocity measures, made by both methods if possible, as described earlier, are required at intervals of not less than 30 seconds during Phase I. The full range of the line-shifter (increased if possible by a

* Recently M. A. Ellison has independently recognized the intrinsic interest of this type and is accumulating data for publication.

subsidiary one) should be frequently used to catch any glimpse of other higher-velocity markings that may be very faint. Frequent notes and sketches are very useful later. A second spectrohelioscope, operated by an observer working in collaboration with the first observer, would be invaluable for recording the progress of the bright emission. By identifying this type of disturbance with a prominence type at the limb (see *infra*) valuable evidence is available in motion pictures which can be repeatedly studied as fresh points for examination arise.

TABLE I

Hα Absorption Markings associated with Bright Eruptions

Serial No.	Year Reference Number	Date	Distance from Central Meridian	Intensity of Bright Eruption	Observed Life of Dark *Hα*, minutes	Phase I (outwards)	
						Velocity First Seen, km./sec.	Peak Velocity, km./sec.
	1936						
1	46	Mar. 18	13° W.	< 1	15	32	...
2	100	May 26	47° W.	3	30	40	...
3	109*	June 5	28° W.	3	31	59	205
4	122	June 17	61° E.	< 1	25	37	...
5	125	June 17	60° E.	1	33	57	100
6	175	Aug. 20	13° W.	1	9	70	(70)
7	200	Sept. 23	22° E.	2	16	68	...
8	252	Nov. 8	34° E.	1	19	52	...
9	1937	Jan. 7	35° W.	< 1	18	70	(70)
10	1938	May 8	62° W.	1	17	33	...
11	1939	May 9	47° W.	2	12	200	(200)
12	1939	June 29	7° E.	1	31	55	165
	MEANS	...	...	...	21	...	−155

NOTES

No. 2. Associated with a radio fade-out.
No. 9. Before the + velocity has gone, a new eruption begins and velocities rise to −135 km./sec. The ensuing motions are complex.
No. 11. Phase III. End not observed owing to cloud.

6. *Non-Typical Cases.*—Brief reference will now be made to the remaining 13 cases of dark *Hα* markings observed in association with abnormal bright emission but whose behaviour departs from the type just described. Three examples are given:—

1936 *May* 25, *No.* 96.—$09^h\ 48^m$ to $10^h\ 22^m$ U.T.: 32° W. of C.M.: latitude 11° N.: associated eruption of intensity < 1.

The outward velocities are rather irregular, showing as a whole no general increase or decrease. The mean is −21 km./sec. The inward velocities, appearing a few minutes after the outward velocities were first located, are smoother, and also show no general trend from a constant velocity. The mean value is +30 km./sec.

1938 *Sept.* 23.—$08^h\ 49^m$ to $09^h\ 47^m$ U.T. associated sunspot 29° E. of C.M.: latitude 10° S. Points of enhanced emission of intensity < 1.

Absorption marking long and curved. Very rapid increase of initial outward velocities, the observer noting that changes of velocity were apparent within 5 or 10 seconds. Individual measures are as follows:—

h m s	km./sec.	h m s	km./sec.
8 49 00	−175	8 57 30	− 33
51 00	> −265	9 06 00	− 55
52 00	−230	08 00	− 37
52 45	−180	10 00	− 33
53 45	−165 *	18 00	− 30
55 00	−162	47 00	− 27

* Extreme velocity: bulk of marking seen at −50 km./sec.

TABLE I

showing Characteristic Velocities as in Fig. 1

Serial No.	Phase II (outwards from Sun)			Phase III (inwards to Sun)				
	Retardation, 10^4 cm. sec.$^{-2}$	Duration, mins.	Velocity Last Seen, km./sec.	First and Last Velocity, km./sec.	Acceleration, 10^4 cm. sec.$^{-2}$	Mean Deviation, km./sec.	Duration, mins.	Distance Fallen, 10^3 km.
1	0·7	6	9	30 : 53	0·3	3·2 (10)	12	30
2	0·3	12	19	29 : 37	0·1	1·3 (8)	17	34
3	0·8	6	28	42 : 190	1·9	5·6 (9)	13	91
4	0·1	20	30	32 : 37	0·1	0·0 (4)	9	19
5	0·5	6	32	36 : 122	0·8	0·8 (9)	17	81
6	3·2	3	26	42 : 85	1·2	5·4 (7)	7	27
7	1·7	4	45	28 : 83	0·7	5·6 (7)	14	48
8	0·1	7	30	29 : 53	0·3	3·2 (10)	14	34
9	0·8	7	22	32 : 62	0·6	2·0 (8)	9	25
10	0·2	17	13	40 : 40	0·0	3·6 (5)	13	31
11	0·6	6	45	45 : 86	1·2	1·3 (3)	6	24
12	...	...	29	48 : 63	0·2	3·5 (4)	11	36
				51 : 109	1·1	3·5 (6)	9	43
	0·8	9	−27	+36 : +80	0·69 ± 0·12	3·0	12	> 41

NOTES

No. 12. Phase II is absent, the rapid retardation ($4{\cdot}2 . 10^4$ cm. sec.$^{-2}$) continuing from the peak value. In Phase III, a marking, seen jointly from the first with that of Phase I, is represented by the upper set of values in Cols. 13–17. The lower sequence represents what appears to be the typical downward branch.

The inward velocities, first seen at $9^h\,00^m$, were irregular, none exceeding +85 km./sec. and with a general tendency to *decrease* with time.

1939 *March* 24.—$10^h\,17^m$ to $11^h\,13^m$ U.T.: 22° N.: 15° W. of C.M.

Associated bright eruption of intensity = 1 first seen at $10^h\,17^m$ and ending at $10^h\,35^m$. The individual measures are shown in fig. 2.

By $11^h\,04^m$ the marking, now dense and curved, had a measured radial velocity increasing to +65 km./sec. towards a sunspot. The mean velocity for the marking as a whole is plotted.

At $11^h\,13^m$ it was seen that a new outward velocity had appeared, but cloud interfered with further observation. There is no obvious acceleration to either the outward or inward velocities measured.

7. *Ancillary Data.*—In the *Greenwich Photoheliographic Results* for the years 1930 to 1936 there are published a number of single radial velocity measures of small dark points or blobs seen in *Hα*, not associated with bright eruptions but in the neighbourhood of sunspots. These markings, like those of similar appearance connected with bright

eruptions, are designated in the fourth column of the spectrohelioscopic results by an asterisk (*e.g.*, *loc. cit.*, *Results* 1933, p. 49, Nos. 5, 8, 11, 21, etc.). They are briefly considered here, because their general characteristics suggest that they are of a kindred nature to the dark markings already discussed in association with bright eruptions.

With some exceptions, when multiple observations are recorded, the duration of these small markings is not known, but the inference is that they were short-lived. In many cases only the − component of radial velocity was measured; in others only the + component, while in 38 cases both the − and the + component were seen together in close juxtaposition by rapidly oscillating the line-shifter. The mean velocities of these pairs of markings are −32·3 and +36·4 km./sec. respectively.

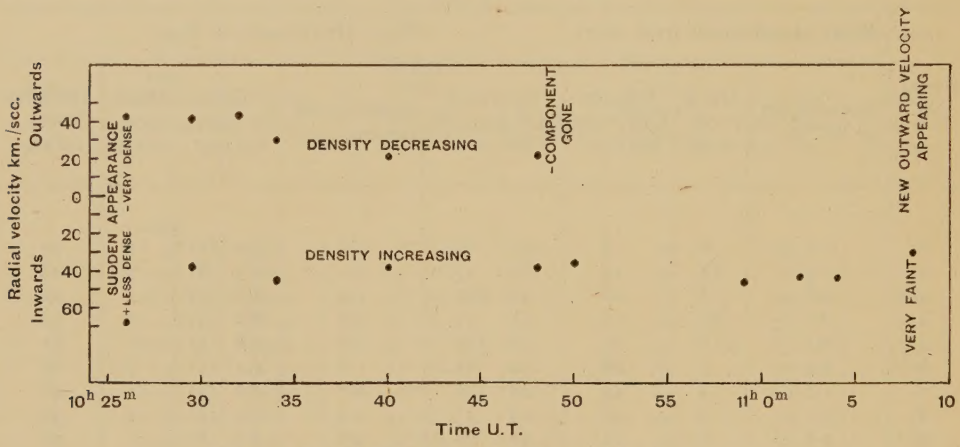

FIG. 2.—*Radial Velocity of dark Hα with bright eruption (non-typical case).* 1939 *March* 24.

In one case (1934, No. 8) the marking was followed for nearly half an hour. The inward velocities denote an acceleration of $0{\cdot}2 \times 10^4$ cm. sec.$^{-2}$. Another case, well observed, is that of 1936 March 17, No. 42, illustrated in fig. 3.

A velocity-frequency graph of 243 of these dark markings is given in fig. 4. The frequencies plotted for velocities 1, 4, 7 . . . km./sec. are the respective summations within each 3 km./sec. range of velocity, viz. 0–2, 3–5, 6–8 . . . km./sec. The following features * are shown:—

(1) The excess of inward to outward velocities in the ratio of nearly 3 to 1.

(2) A peak at about 34 km./sec. in both the − and + velocities, the peak being very pronounced in the case of the inward velocities. In about half the cases of inward velocities > +50 km./sec., the *Hα* marking was apparently descending into either the penumbra or the umbra of a sunspot. The peaks at about 34 km./sec. are interesting in view of S. Chandrasekhar's researches on the solar chromosphere,† from which he derived a tendency for particles of medium velocity of the order 30 km./sec. to be ejected from the chromosphere.

With respect to the marked excess of inward motions it has been noticed by prominence observers ‡ that "in the lower bright arches and loops of prominences of Classes III*b* and III*c*, the motions of *descent* are always clear, brilliant and rapid, while any corresponding *ascent* of matter where the rising side of the completed trajectory should be is either so faint that no motion can be detected or, as is more frequently the case, it is entirely absent."

The inward excess of downward motions is, however, not confined alone to these types of prominences.

* See also *M.N.*, 94, 472, 1934.

† *M.N.*, 94, 25, 1933.

‡ McMath, *Proc. American Phil. Soc.*, 79, 494, 1938.

8. *Comparison with Prominences at the Limb.*—It is of primary interest to identify the outward and inward moving dark *Hα* patches considered in this paper with prominence types seen in profile at the Sun's limb. From the characteristics of various prominence types described * by R. McMath and H. E. Sawyer, there appears to be a strong general resemblance in behaviour between the absorption markings considered

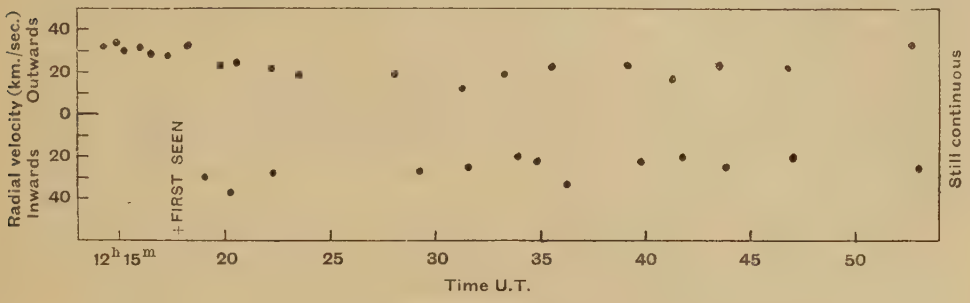

FIG. 3.—*Long-continued pair of dark Hα markings not associated with special bright emission. 1936 March 17.*

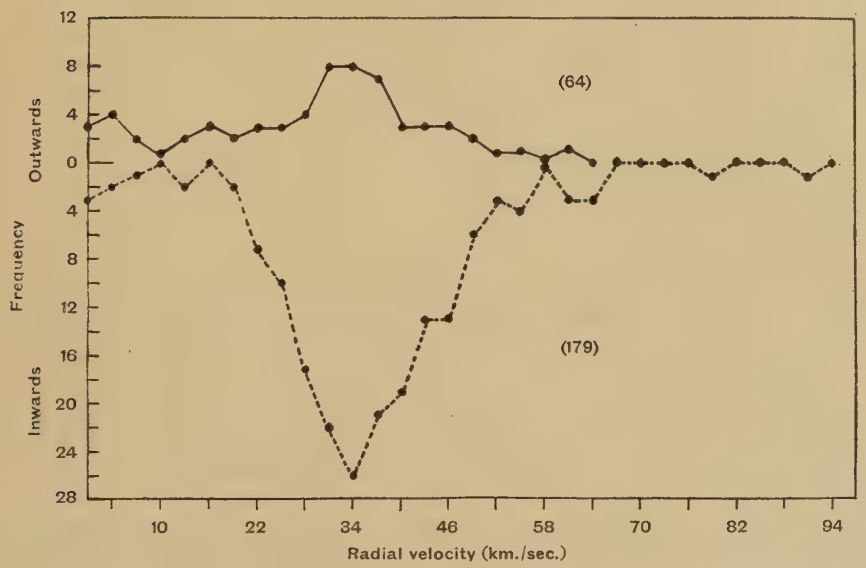

FIG. 4.—*Velocity-Frequency Diagram of 243 small dark Hα markings in sunspot groups. (No special bright emission.)*

here and the type of short-lived prominences known as "surges" and classified as Class III*d*. Only a few time-height diagrams of surges have ever been published; the results of four are given by McMath and Pettit in *Ap. J.*, **85**, 291, 1937. The heights deduced in column 17 of Table I of this paper are of the same order as those of surges; and the maximum observed velocities are also of the same order. The following description is taken from the paper, *loc. cit.*, p. 197, by McMath and Sawyer:—

"Surges are short-lived phenomena which frequently thrust upward from a spot area and subside, or in some cases apparently return to the chromosphere over the original trajectory. In general they are very bright, some examples even exceeding the brightness of the chromosphere. Small examples of their type are frequent occurrences in the

* *Publ. of the Observatory of the University of Michigan*, **7**, 195, 1939; also McMath and Pettit, *Ap. J.*, **85**, 296, 1937.

active region surrounding a sunspot . . . in general the velocity of ejection is greater than that of recession. . . ."

It seems likely that the small examples of frequent occurrence described by McMath and Sawyer are to be identified with the disc markings of the preceding paragraph 7. Whilst there are several points of strong similarity between the Greenwich disc observations and the Lake Angelus limb observation of surges, there remain for correlation (*a*) the discontinuity of the upward and downward motions as given by the disc observations, (*b*) the fading of the upward moving marking at about −30 km./sec. and, somewhat preceding this fading, the first signs of the downward motion at about +35 km./sec. A third point concerns the downward acceleration found in about half the disc markings considered herein with bright eruptions. Until quite recently, McMath and his collaborators * were unable to find from prominence limb observations any evidence for a gradual acceleration of velocities.

In a new paper †, however, on the measured space motions of prominences in *Hα*, McMath and Sawyer have found accelerating downward motions of knots in two prominences. The accelerations found are of the same general order of magnitude as those derived from disc markings in Table I of this paper.

Summary

Results are given of radial velocity measures, made at Greenwich, of *Hα* absorption markings on the Sun's disc associated with bright eruptions that occur near sunspots.

Half of the cases observed show characteristic motions summarized in the time-velocity diagram (fig. 1). The chief features are:

(1) The high initial outward velocity followed by a sudden drop.

(2) The constant acceleration downwards that occurs later; the acceleration is less than that due to solar gravity.

(3) The discontinuity in the time-velocity graphs of the outward and inward velocities, and

(4) The non-visibility of the outward moving marking when its velocity has fallen below an average value of about 30 km./sec. and the first appearance of descending *Hα* at about the same limiting velocity. These and other points are briefly discussed.

The other miscellaneous half of the observed cases, though having the general characteristic of an overlap of − and + velocities, show varying departure from the above type, including a general absence of downward acceleration.

As a whole, both classes of disc markings are to be identified with "surges" seen as limb prominences, but the correlation of detailed features as enumerated above awaits future investigation.

A large number of singly observed small *Hα* absorption markings (seen near sunspots but not with abnormal emission) may be small or incipient surges. Their velocity-frequency distribution shows a marked peak at about 34 km./sec., and inward motions greatly predominate.

Brief suggestions are made as to further observations of these interesting kindred types of *Hα* absorption markings found near sunspots.

Acknowledgments.—To the Astronomer Royal I am grateful for the opportunity given me of preparing this paper. I wish to record the helpful interest shown in these observations for some time past by Professor E. A. Milne, and recently by Dr. A. Hunter who also helped me in the final revision of the MS. Mrs. M. E. Higby of the Observatory staff has assisted me in preparing the data for publication.

Royal Observatory,
Greenwich:
1942 *January* 7.

* *Proc. Am. Phil. Soc.*, **79**, 493, 1938, and *Publ. Obs. Univ. Michigan*, **7**, 199, 1939. For a theoretical aspect, see Giovanelli, *Ap. J.*, **91**, 87, 1940.

† *Loc. cit.*, **8**, 123, 1941.

SOME STUDIES OF THE MOTIONS OF HYDROGEN FLOCCULI BY DOPPLER DISPLACEMENTS OF THE *Hα* LINE

M. A. Ellison, M.Sc.

(Received 1942 January 22)

1. *Introduction.*—The present paper describes investigations into the movements of two characteristic types of hydrogen flocculi by continuous measurements of radial velocity.

Since the development of the spectrohelioscope by Hale, so beautifully described in his four papers on *The Spectrohelioscope and its Work* *, the results of important investigations by H. W. Newton †, M. Waldmeier ‡ and others have been published dealing with the movements of prominences and flocculi, as deduced from the Doppler shifts of the *Hα* line. Insufficient attention has been given, however, to that aspect of Hale's work § in which he foreshadowed the use of the spectrohelioscope as a powerful weapon for the study of the life-histories of individual prominences, either when seen against the sky or as dark flocculi projected against the background of the solar disk. This has been so in the main for two reasons. In the first place, the last ten years have witnessed the highly successful development of continuous photography for following the motions of prominences at the limb, either by Lyot's coronagraph camera or by means of the automatic spectroheliographs of the McMath-Hulbert Observatory. The importance of the visual observations has thus been obscured, though in one important respect the visual method is superior to the photographic; for the spectrohelioscope provides, in general, direct readings of the line-of-sight velocity of moving matter, while the prominence films only allow the velocities to be inferred from the gradients of the height-time diagrams. Secondly, while it must be conceded that movements observed in dark flocculi with the spectrohelioscope are usually of a complex nature, often differing widely between adjacent portions of the same flocculus, so that it is difficult to pick out and follow with certainty the movements of one particular feature over a long period of time, yet it will be shown that in many of the flocculi of short life, such as those which occur in the vicinity of active spots and chromospheric eruptions, the movements are of a simpler nature and lend themselves to continuous measurements of radial velocity. In these cases, where the ascent and descent of the prominence material may be covered in a period of 20 minutes or less, the difficulty confronting the observer is not to interpret what he sees so much as to attain a frequency of measurement which will enable a detailed radial velocity-time curve to be plotted. In the present work a frequency of one measure per minute has been aimed at. This rate may be readily exceeded with the existing apparatus over short periods when the rapid changes of radial velocity require it.

2. *Instrumental Arrangements.*—The Sherborne spectrohelioscope has been described in an earlier paper ||, and some later modifications have been introduced as required by the present investigations. A plane diffraction grating (ruled area 8 cm. × 5 cm.) has been substituted for the prism train which was formerly in use as the dispersion element. The greater dispersion of the grating and the elimination of so many optical surfaces have led to improved sharpness and greater detail in the images. The dispersion is carried out on the Littrow plan, using a single plano-convex collimating lens

* *Ap. J.*, 70, 265, 1929; 71, 73, 1930; 73, 379, 1931; 74, 214, 1931.
† *M.N.*, 94, 472, 1934.
‡ *Zs. für Ap.*, 15, 299, 1938.
§ *Ap. J.*, 71, 73, 1930.
|| *B.A.A. Journal*, 50, 107, 1940.

of 13 feet focus which takes the place of the two concave mirrors in the standard Hale instrument. By the removal of these two reflecting surfaces a considerable increase in the brightness of the image has been effected, and suitably placed stops have been employed to gather unwanted reflections of white light from the two surfaces of the collimating lens.

A further gain in light-grasp arises from the use of motor-driven oscillating slits, on the Sellers' plan *, in place of the Anderson rotating prisms. It is thereby possible to scan a larger area of the Sun's disk without any diminution of the brightness of the retinal image. The normal amplitude of oscillation is 0·75 inch, which covers one-third of the disk at a single view. The wider field is undoubtedly of great value, for it materially increases the chances of picking up active flocculi in their initial stages by the process of moving the line-shifter slowly to and fro.

Furthermore, the amplitude of the vibrating slits has been made continuously variable from zero up to full field-width to allow for the frequent changes of seeing which are experienced: full scanning is normally used for features on the disk, while limb prominences stand out with great brilliance when the field-width is reduced to 0·1 inch. The line-shifter is a plane-parallel plate, similar to that used by Hale, and optical arrangements have been contrived to project a magnified image of its scale on to the front of the instrument, in line with the left eye, so that readings of the displacement of the *Hα* line may be made with the least possible delay while the flocculus is kept under continuous observation in the eyepiece. The first-order spectrum is used, giving a dispersion at the viewing slit of 4·4 A./mm. The scale of the line-shifter is 10 division (0–10) = 1·01 A. = 46·0 km./sec., readings being interpolated to one-tenth of a division. The probable error of a single reading of radial velocity for a well-defined flocculus is about 2·0 km./sec.

A bifilar micrometer is used in the eyepiece of the instrument for measuring the heights of prominences above the limb and for detecting the lateral motions of flocculi across the disk. The two parallel wires are mounted in a rotating frame which is placed immediately in front of the viewing slit, the wires being in simultaneous focus with the monochromatic image. One revolution of the micrometer screw = 9·75 seconds of arc, equivalent to 7000 km., for a mean solar apparent diameter of 32 minutes of arc.

3. *Surges.*—These prominences were first recognized by McMath as the members of a new type (Class III*d*) when their movements began to attract attention on the prominence films taken at Lake Angelus in 1936.† At Sherborne, where a special watch has been kept for surges since early 1940, it has become apparent that they are among the most frequent in occurrence of all the prominence types. Nearly fifty examples have been observed at the limb and another twenty-six have been partially or completely observed as dark flocculi seen by contrast against the disk. On the other hand, they are among the most short-lived of chromospheric phenomena; of nine cases observed from start to finish upon the disk the durations have ranged from 8 minutes to 37 minutes with an average life of 20 minutes. For this reason it seems they are seldom to be found on spectroheliograms of limb prominences and were late in gaining recognition as a characteristic type of chromospheric activity.

When seen at the limb, surges usually appear as narrow "spikes" of flame, rising in nearly vertical trajectories to heights of 20,000 or 30,000 km., to be followed by a more gradual descent along the same path. Occasionally two or more are seen simultaneously, emanating from a single small area in an active spot-group just within the limb. Larger examples have been recorded, reaching heights in excess of 50,000 km., but they have usually been inclined at large angles to the solar radius; it is very probable that these should be classed as quasi-eruptive prominences and that they arise from chromospheric eruptions, themselves invisible behind the limb. Considered as prominences, the surges are of unusual brilliance, sometimes exceeding the brightness of the

* *B.A.A. Journal*, **48**, 243, 1938. † *Ap. J.*, **85**, 279, 1937.

chromosphere itself; and it may be remarked in passing, that prominence types which radiate most brilliantly at the limb are those which produce the maximum absorption when seen as disk flocculi.

When the programme of radial velocity measures was begun it was soon established that the counterpart to these interesting events at the limb was frequently to be seen in terms of dark flocculi upon the disk. Observing in light of *Hα* with the spectro-helioscope, short-lived circular or oval flocculi, 20–30″ in diameter, are often observed within the confines of an active spot-group. Of great density, one of these circular flocculi may easily be mistaken for the umbra of a sunspot until a small movement of the line-shifter reveals its true nature; for, unlike the sunspot, the dark flocculus becomes invisible by light which is removed 1 A. or more from the centre of the line. Such flocculi were first mentioned by H. W. Newton *, who has also included them in his discussion on the radial velocities of dark flocculi near sunspots †; many more examples are recorded in the *Greenwich Photoheliographic Results* from 1930 onwards.

It is clear from the disk observations that these flocculi usually occur at a distance of about 50,000 km. from the umbra of an active sunspot; they are not in any way connected with chromospheric eruptions, but are frequently confined to one small area within the group. A good example of this localised activity was to be found in the group of C.M. passage 1941 July 3, where a region 60,000 km. west of the northern component of the group gave rise to a succession of "circular" flocculi during the period June 29–July 4. No similar flocculi were seen elsewhere in this group, though there were present active dark flocculi of other types. Several sunspot groups have also been recorded in which activity in "circular" flocculi, seen while the group was still present on the disk, has been succeeded by the appearance of surge prominences

TABLE I

Surges

Reference Number	Date and Time of Beginning and Ending, U.T. 1941				Position of Flocculus relative to Sunspot or Group		Shape	Associated Sunspot or Group	
		d	h	m	′			Lat.	Long. from C.M.
								°	°
1	Jan.	3	12	13·0	0·6	p	r	+16	W. 13
			12	29·5					
2	Jan.	3	13	30·0	1·0	f	r	+16	W. 14
			13	34·3					
3	Jan.	3	13	41·0	0·6	p	r	+16	W. 14
			13	49·5					
4	Mar.	13	14	53·0	0·7	s	r	+12	W. 15
			15	10·4					
5	Sept.	30	16	03·5	1·0	p	o	+ 1	E. 19
			16	27·0					
6	July	1	15	53·0	1·0	f	o	− 6	W. 13
			16	11·0					
7	July	3	9	28·5	1·5	p	o	+12	E. 8
			10	00·0					
8	July	3	11	00·0	1·5	p	o	+12	E. 7
			11	20·0					
9	July	7	16	26·0	1·0	sp	c	+ 3	E. 45
			17	03·1					
10	June	24	19	28·0	0·5	s	c	+ 8	E. 16
			19	36·9					

The letters r, o, c signify round, oval and crescent-shaped flocculi respectively.

* *M.N.*, 91, 595, 1931. † *M.N.*, 94, 472, 1934.

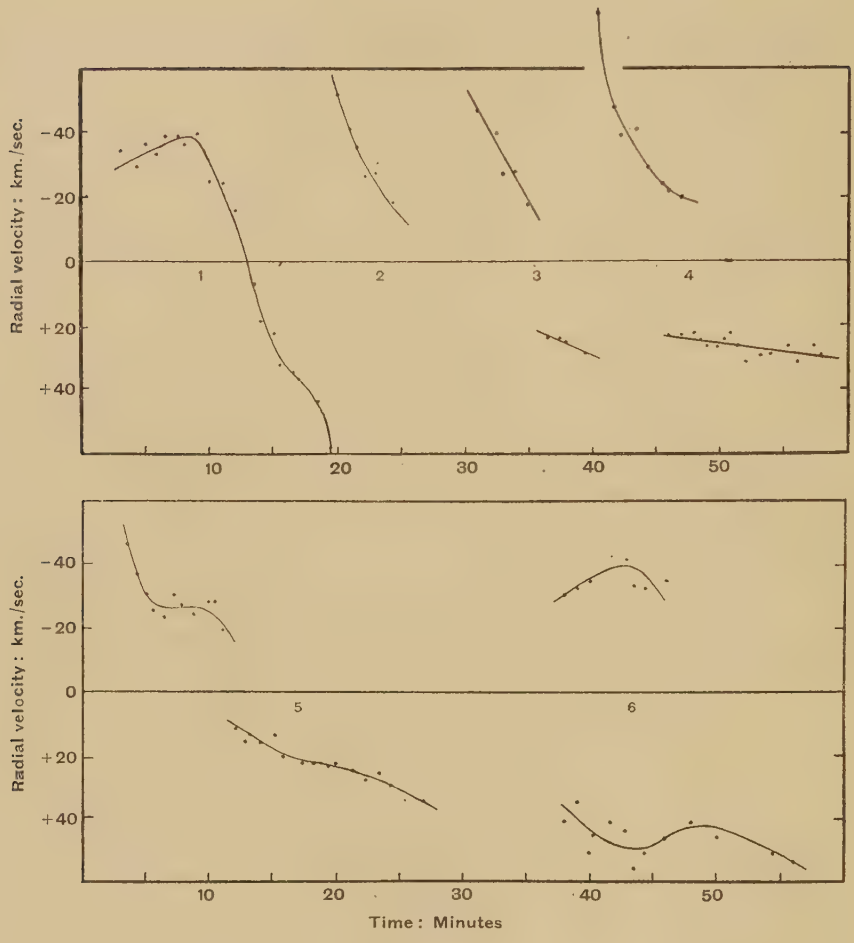

FIG. 1A.—*Surges.*

in substantially the same region when the group had reached the west limb. Such evidence drawn from the continuity of limb and disk phenomena, together with the localised appearance of both limb surges and "circular" dark flocculi, leaves us in little doubt that in the first we are observing the elevation and in the second the plan view of one and the same type of prominence activity. This conclusion is further supported by a consideration of the movements of the flocculi, as deduced from the radial velocity measures about to be described.

4. *Radial Velocity-Time Curves.*—The ten curves illustrated in figs. 1A and 1B refer to flocculi of surge type observed near the centre of the solar disk, and for which there is evidence that a substantial part of the life-history has been recorded. Details of position, times of beginning and ending, etc., are included in Table I.

Each curve is divided into two parts, that which is plotted above the horizontal axis giving the radial velocities during the ascent (R.V. −), and that below the axis the radial velocities during the descent (R.V. +), of the prominence gases. It may not be out of place here to remark that these curves between radial velocity and time, which for brevity we shall call Doppler time-curves, should be clearly distinguished from the height-time diagrams published by Pettit and McMath from their cinematograph records of prominences at the limb. The relationship will be dealt with in section 5.

Observations at the limb indicate that the smaller surges follow approximately

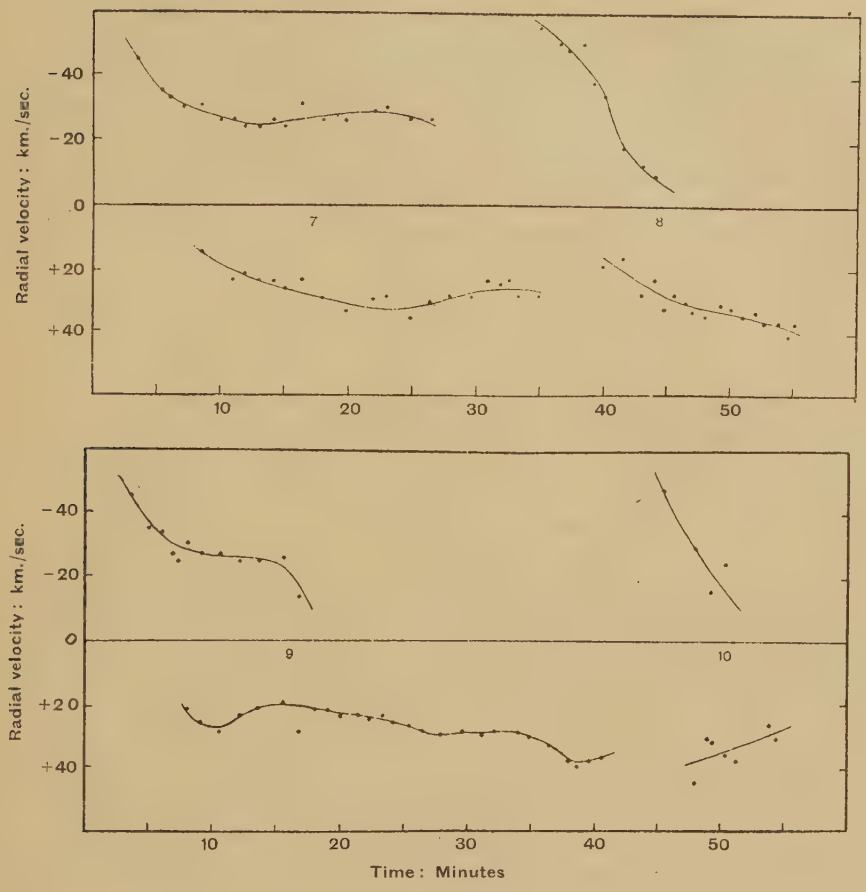

FIG. 1B.—*Surges.*

vertical trajectories. Near the centre of the disk, therefore, these prominences will be moving along the line of sight, and, in the absence of simultaneous lateral movements across the disk, we may conclude that the radial velocity plotted against the time will provide a true picture of the motion of the prominence material. A typical observation of a surge on the disk may be described in the following terms. The first appearance is a faint round or oval spot displaced 1 A. (=45·7 km./sec.) or more to the short-wave side of the centre of the *Hα* line. This spot darkens rapidly while the radial velocity decreases, the greatest density being reached about half-way through the ascent when the radial velocity has fallen to about −30 km./sec. The flocculus now resembles the umbra of a sunspot, and the density thereafter decreases until it fades away at a value of about −20 km./sec. The descending gases next make their appearance, faintly at first and with increasing density as the radial velocity rises, slowly in this case, from a value of +15 or +20 km./sec. Half-way through the descent the flocculus again shows much the same shape and density as it had midway through the ascent. The ascending and descending gases also coincide in position *, which suggests that the prominence material returns to the chromosphere along the same trajectory, as has been noted at the limb. Finally, there is a quick fade-away near the end as the flocculus takes its departure. In some examples, *e.g.* Nos. 7, 8, 9, the descending motion sets

* Mr. Newton informs me that some of the examples observed at Greenwich suggest movement along a narrow arch or loop.

in a considerable time before the ascending motion has disappeared, so that the + and − radial velocities are simultaneously visible at the same point for some minutes.

It is not proposed to enter into any detailed discussion of the Doppler time-curves until much fuller observational material is available, but it seems permissible, meanwhile, to draw attention to some conclusions which may be regarded as fairly well established:

(1) The initial high velocity of ascent is subject to a retardation (gradient of the curve) of the same order of magnitude as that which would be experienced by a body rising freely in the chromosphere under the action of solar gravity alone. This high initial retardation is not maintained for the whole of the upward flight, but decreases with height.

(2) The downward velocities are less, and are subject to smaller accelerations, than the upward velocities.

(3) There is no evidence for constant velocities of ascent or descent with abrupt changes of velocity, such as have been found by Pettit and McMath.

5. *Distance Integrals.*—Let us suppose that the motion of a prominence at the limb is referred to rectangular co-ordinates X, Y, Z, mutually at right angles. We shall assume the origin of the axes to be located in the chromosphere, the X-axis to coincide with the solar radius and the Y-, Z-axes to be tangential to the solar surface, Z coinciding with the observer's line of sight. It is clear that the x, y co-ordinates of the prominence may be found from limb spectroheliograms; curves may then be plotted between $x-t$ and $y-t$, the gradients of which will provide values of dx/dt and dy/dt at any time. This was the method of approach first adopted by Pettit and later followed at the McMath-Hulbert Observatory using the cinematograph records. The value of dz/dt may be measured from the Doppler displacements, either visually with the spectro-helioscope, or now photographically with the Stone spectroheliograph.* Next let the solar rotation carry our frame of reference round to the centre of the disk, so that the X-axis coincides with the line of sight. Under these conditions it will be possible to measure the co-ordinates y, z with the spectrohelioscope or spectroheliograph and dx/dt from the Doppler displacements. Furthermore, graphical integrations of the curves between dx/dt, dy/dt, dz/dt and t will yield the distances travelled along X, Y, Z respectively, as well as the distances x, y, z from the origin, provided the appropriate constants of integration can be found.

The areas enclosed between each of the curves (1–10) and the first and last time ordinates have been measured with a planimeter and the results reduced to kilometres. These values for the ascent and descent may be called the *distance integrals* of the flocculus and are entered in Table II. The extent to which these values represent the actual distances travelled by the prominence gases evidently depends upon two factors: (*a*) The angle between the line of sight and the trajectory. (For the spot-like surges there is evidence that these two directions will be nearly coincident for the central regions of the disk.) (*b*) How far do we observe the same mass of radiating gas during ascent and descent? This may be fully the case for some of the surges (*e.g.* Nos. 1, 3 and 5), though it can scarcely be true for all; for if the Doppler time-curves for ascent and descent overlap in time (*e.g.* No. 7), we must suppose that different masses of gas are concerned in emitting the two wave-lengths which are simultaneously visible.

The averages for the *distance integrals* for surges, given in Table II, are 16,810 and 26,690 km. for ascent and descent respectively, values which are in satisfactory agreement with the average elevation of surges seen at the Sun's limb, *i.e.* about 30,000 km. The large difference between the integrals would be very surprising if it represented a real difference between the distances of ascent and descent of the moving gases; but there may exist a simpler explanation, inherent in the method of observation, which would be adequate to account for the smaller value of ascent. The appearance of a surge in the field of the spectrohelioscope is not preceded by any visible warning, and

* *Publ. Univ. Michigan Obs.*, 8, 57, 1940.

TABLE II

Distance Integrals for Surges

Reference Number	Distance Integrals	
	Ascending Motion, R.V. −	Descending Motion, R.V. +
	Km.	Km.
1	18,750	12,150
2	7,500	...
3	8,200	4,500
4	13,900	19,350
5	12,750	20,500
6	17,250	48,300
7	39,900	43,200
8	18,600	26,800
9	22,400	52,500
10	8,850	12,900
Averages	16,810	26,690

it can only be seen at all in the initial stages by a displacement of the line-shifter 1 A. or more to the violet side of the *Hα* line. Thus several minutes must inevitably elapse before one can be certain of the identity of the flocculus and begin measurements of its radial velocity. There is, of course, no similar loss of time while observing the flocculus along its downward path.

To fix our ideas in regard to acceleration, it may be helpful to consider the case of a rifle-bullet projected vertically upwards in the chromosphere. The bullet may be supposed to emit monochromatic radiation and to experience no other forces than that of solar gravity. The Doppler time-curve for such a moving source, observed with the spectrohelioscope from a point on the extension of its trajectory, will clearly be a straight line. This will intersect the zero axis corresponding to the time of maximum height, and the gradient of the line will be the solar value of g ($2{\cdot}74 \times 10^4$ cm./sec.^{2}). In fig. 2 the broken line has been drawn with the appropriate gradient to represent the Doppler time-curve for such an object. It is not to be expected that the motion of any real flocculus will approximate to this ideal case, but it serves as a useful reference line for the estimation of accelerations.

6. *Quasi-eruptive Flocculi.*—Giovanelli, in the course of his notable studies of chromospheric eruptions with the spectrohelioscope at Mount Stromlo, has drawn attention * to the accompanying eruptive dark flocculi (or eruptive prominences when seen near the limb) which are a characteristic feature in many of the observed cases. He records 112 bright eruptions, occurring in the period March–December 1938, of which 21, or 19 per cent., gave rise to eruptive flocculi.† A similar count, made at Sherborne during the less active years 1940–41, has recorded 102 eruptions, of which 30 have given rise to eruptive dark flocculi similar to those Giovanelli has described.

When observed on the disk these flocculi make their appearance at about the time of maximum intensity of the bright hydrogen, at a distance from the eruption centre which may be as great as 100,000 km. They are large irregular patches of great density, usually showing a high velocity of approach, and are quite easily distinguished from the small "spot-like" flocculi already described. After an interval of 15 or 20 minutes recessive dark markings begin to appear in the vicinity while the approach markings fade away. In many cases simultaneous high velocities across the disk have been

* *Ap. J.*, 91, 334, 1940.

† An earlier description of these flocculi by H. W. Newton is to be found in *M.N.*, 95, 650, 1935.

recorded in the micrometer eyepiece, of the same order as those measured in the line of sight, from which we conclude that these prominences, unlike the smaller surges, may be ejected at almost any angle to the solar radius. Seven cases have been noted of chromospheric eruptions occurring within 15° of the limb, in which both the bright

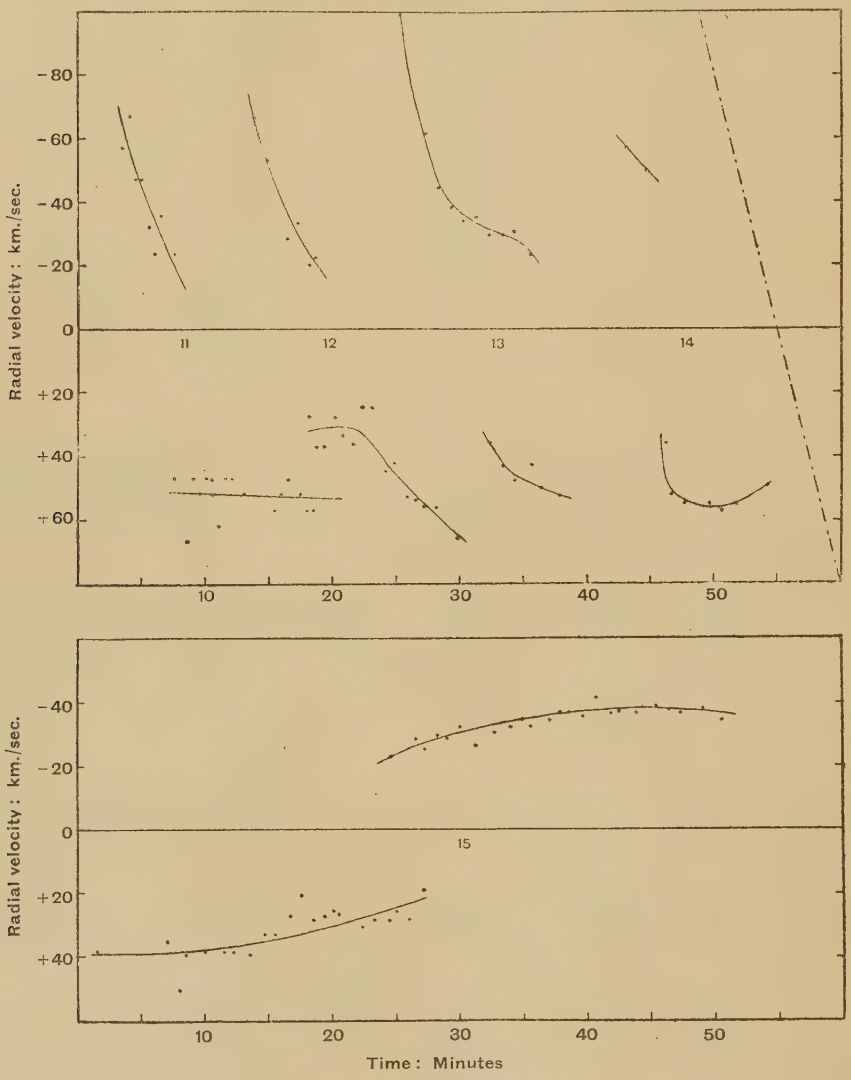

FIG. 2.—*Quasi-eruptive Flocculi.*

hydrogen and the eruptive dark flocculus have been simultaneously visible, the latter rising swiftly to appear as an eruptive prominence against the sky. In two examples the radial velocities of both prominence and dark flocculus have shown the same value at the limb, still further illustrating the continuity of the two phenomena.

Because of the large size and complex internal motions of some of the eruptive flocculi it is no easy matter to obtain continuous measurements of radial velocity which one can refer with certainty to a definite part of the flocculus. However, it has been possible to make satisfactory runs on a few of the smaller ones which have shown a common velocity in all parts and absence of appreciable lateral motions. The Doppler

TABLE III

Quasi-eruptive Flocculi connected with Chromospheric Eruptions

Reference Number	Date and Time of Beginning and Ending, U.T. 1940	Position relative to and Distance from Bright Eruption	Associated Bright Eruption: Lat.	Associated Bright Eruption: Long. from C.M.	Time of Eruption and Importance	Distance Integrals
	d h m	10^3 km.	°	°	h m	km.
11	Sept. 1 11 46·0	15 s	− 6	0	11 40	9,050
	12 01·0				(1)	33,600
	1941					
12	Apr. 17 10 08·0	30 p	− 8	W. 53	10 08	11,760
	10 19·0				(2)	29,900
13	Sept. 15 10 14·0	15 sf	+18	E. 23	10 14	26,400
	10 26·5				(1)	15,100
14	June 24 10 27·0	20 p	− 5	W. 29	10 23	5,050
	10 40·0				(2)	25,800
15	Mar. 16 11 26·5	20 sp	+11	W. 59	11 25	51,300
	12 15·4				(1)	52,800

Where the beginning of the bright eruption has been observed, this fact is indicated by printing the time in heavy type.

time-curves for these are illustrated in fig. 2 (Nos. 11–14), but it should be remembered that they refer to flocculi which were undoubtedly smaller both in duration and extent than the average of their type. The circumstances attending these observations are recorded in Table III, together with the *distance integrals* of ascent and descent. It will be seen that the Doppler time-curves are of the same general form as those for surges, but that they exhibit velocities of ascent and descent somewhat larger than before. The velocities of ascent are subject to initial retardations which are approximately equal to or, as in No. 13, slightly greater than the value of g on the Sun's surface. In two of the thirty cases the motion of the flocculus has been in reverse order, descent followed by ascent. This is well illustrated in curve No. 15, which refers to a very dense flocculus, following upon an eruption of importance 1 on 1941 March 16, at 59° west of the central meridian. The distances travelled in the line of sight for descent and ascent both exceed 50,000 km. It is, of course, possible that this flocculus was projected outwards at a large angle to the radius in a direction away from the observer, and that the reversal of the usual motions was an apparent effect due to "projection factor." Such an explanation is not altogether satisfactory, since it implies that the prominence gases, having reached the summit of their trajectory, must have returned along the same steeply inclined path to the chromosphere, which is hardly in accordance with observations of similar trajectories at the limb. The expected transverse motions were not observed.

7. *Statistical Discussion of Measures.*—In the years 1940–41 some 500 measures of radial velocity were made on active short-lived dark flocculi which occurred in the vicinity of sunspots; these were apparently unconnected with any chromospheric eruptions. The measures of flocculi, all within 60° of the centre of the disk, have been grouped positively and negatively and then subdivided to show the number of measures occurring within the ranges of 0–4, 5–9, etc. km./sec. up to 90 km./sec. The results of this analysis are illustrated graphically in fig. 3 (Nos. 1 and 2).

The descending motions show a well-defined maximum frequency at about 30 km./sec., and the ascending motions at about 35 km./sec. The descending motions outnumber those of ascent in the proportion of 313 to 187.

It is interesting to note that these results are in good agreement with similar counts made by H. W. Newton * in the years 1930–33. But, whereas both counts agree in placing the maximum frequency of occurrence in the neighbourhood of 30 km./sec., the Greenwich analysis differs from mine in showing a high percentage of radial velocities in the range 0–9 km./sec. It seems that this divergence for low values may be fully

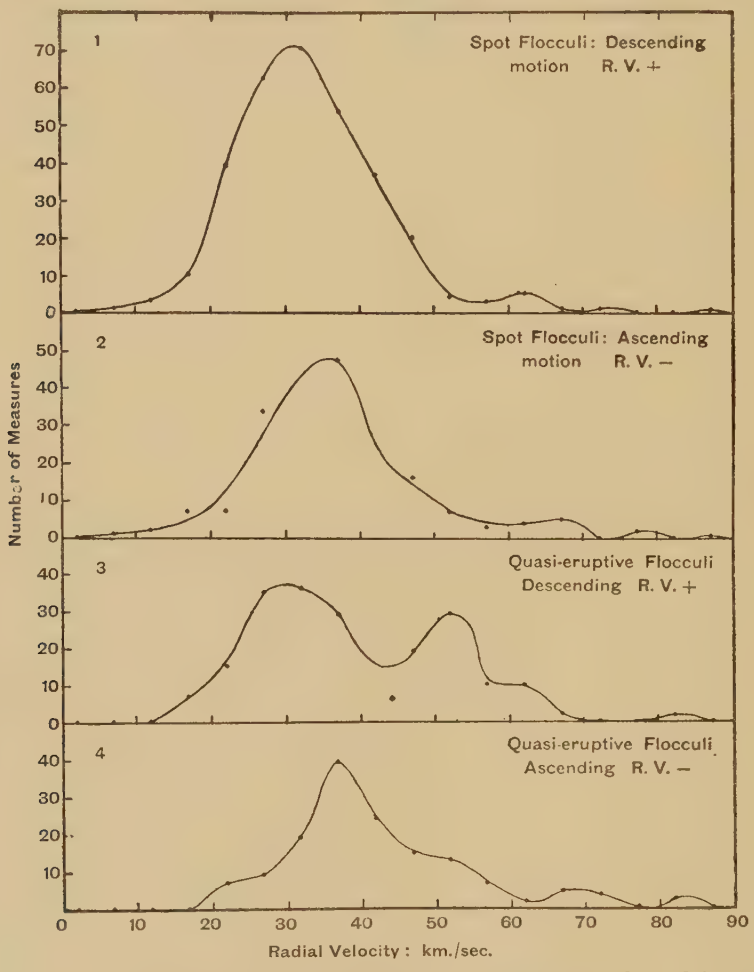

FIG. 3.—*The ordinates represent the number of measures of radial velocity lying within the ranges 0–4, 5–9, 10–14, etc. km./sec.*

accounted for by the different purposes of the two observing programmes. The Greenwich programme was specially designed to include all flocculi near sunspots (excluding the large quiescent type); at Sherborne, active flocculi have been especially sought for, while static or slow-moving flocculi have been neglected.

The results of a similar analysis for the quasi-eruptive flocculi (*i.e.* those definitely connected with the occurrence of a near-by chromospheric eruption) are incorporated in fig. 3 (Nos. 3 and 4). Here we have 355 radial velocity measures divided into positive and negative groups and distributed as before, according to the frequency of occurrence, into the ranges 0–4, 5–9, etc. km./sec. There is still an excess of descending motions, though less marked than before, in the proportion of 203 to 152. The ascending

* *M.N.*, 94, 472, 1934.

motions exhibit a sharply defined maximum between 35–40 km./sec., but with a much larger percentage of the higher velocities, between 50–90 km./sec., than was the case for the spot flocculi. The descending motions also have a wider distribution of frequencies, with a principal maximum about 30 km./sec. and a secondary peak at 53 km./sec.

The observed excess of descending motions (R.V. +) calls for some comment. A considerable proportion of flocculi near sunspots are of surge type—that is to say, they are projected upwards with high initial velocities of ascent and fall back more slowly. Thus the time of ascent is shorter, on the average, than that of descent (this is clearly the case from a study of the Doppler time-curves). From this cause alone, in any statistical investigation of random measures, we should expect the positive values to outnumber the negative values of radial velocity. While this effect may not account for the whole of the observed excess of positive velocities near sunspots, it would probably go far towards redressing the balance, and would be adequate to account for the much smaller excess of positive velocities observed in connection with the quasi-eruptive flocculi.

In conclusion, I should like to acknowledge my indebtedness to H. W. Newton for much helpful advice while erecting the Sherborne spectrohelioscope; and to the Government Grant Committee of the Royal Society for a grant in aid of this work.

Summary

Radial velocity measurements have been made at one-minute intervals on surges near sunspots and quasi-eruptive flocculi in the vicinity of chromospheric eruptions, all observations being made on the disk. The curves are discussed and *distance integrals* and accelerations deduced. The *distance integrals* are in satisfactory agreement with the heights observed for the limb prominences of corresponding type. Accelerations have been found in the initial stages of ascent equal to, and in one case exceeding, the value for free fall under gravity in the chromosphere.

A statistical analysis of all the radial velocity measures near sunspots shows a maximum frequency of occurrence between 30–40 km./sec., thus confirming similar results previously obtained by H. W. Newton.

CHROMOSPHERIC ERUPTIONS OBSERVED AT SHERBORNE, 1940

M. A. Ellison, M.Sc.

(Received 1942 January 22)

The regrettable cessation of the publication * of the *Bulletin for Character Figures of Solar Phenomena* (I.A.U.), together with the enforced idleness of so many of the Hale spectrohelioscopes, makes it desirable to publish whatever records of chromospheric activity are available. Details of the chromospheric eruptions presented in the following lists have been extracted from the records of solar phenomena made with the Littrow-type spectrohelioscope at Sherborne.

In Column 3 is entered the time of the first observation of the eruption, and in cases where the beginning of the eruption has been definitely recorded this fact is denoted by the use of heavy type. The time given in Column 4 for the end of the eruption is necessarily a somewhat uncertain quantity, since the rapid rise to maximum intensity is usually followed by a slow decline.

Column 7 contains an estimate of the importance of the eruption on the scale of 1 to 3 adopted in the I.A.U. *Bulletins*.

In the same column the letter *d* denotes the appearance of active dark flocculi at, or near, the time of maximum intensity of the eruption.

Column 8 records the maximum area of the eruption in millionths of the visible hemisphere, or, for the eruptive prominences (denoted by an asterisk), the maximum height in seconds of arc above the limb.

The inclusion of eruptive prominences in this list seems to be justified by recent correlations of limb and disk phenomena. This work suggests that a large proportion of these prominences arise in the neighbourhood of chromospheric eruptions, themselves invisible, at the limb or behind it.

No.	Date	First Observation	End of Eruption	Lat.	Long. from C.M.	Importance	Max. Area in millionths, or Height in secs. of Arc
	1940	U.T.	U.T.				
		h m	h m	°	°		
1	Mar. 3	**12 00**		− 3	E. 90		* 70″
2	27	**12 10**	13 30	+ 8	W. 16	2	
3	27	17 10	17 45	+12	W. 19	3	1200 m.
4	Apr. 22	13 30	15 58	+14	W. 9	2 *d*	
5	May 4	**14 30**	14 48	−14	E. 90		* 211″
6	12	**10 50**	11 00	+18	E. 90		* 50″
7	14	13 52	14 15	− 8	W. 32	1	
8	14	13 52	14 15	−10	W. 26	1	
9	17	9 14	10 55	+17	E. 31	3 *d*	
10	17	**9 24**	9 40	+ 9	E. 17	1	
11	23	**16 50**	17 00	+14	W. 90		* 30″
12	31	**17 35**	18 00	−12	W. 55	1	
13	June 2	11 53	12 10	−12	W. 82	1	
14	4	**14 15**	14 45	+15	W. 90		* 130″
15	8	13 32	13 55	−19	W. 40	1	
16	8	**13 58**	14 15	− 7	W. 81		* 40″
17	8	**17 10**	17 20	− 7	W. 83		* 75″

* The *Bulletin* is still being published, but the observations recorded in this paper were either not received or received too late for inclusion in the summary for 1940.—EDITORS.

No.	Date	First Observation	End of Eruption	Lat.	Long. from C.M.	Importance	Max. Area in millionths, or Height in secs. of Arc
	1940	U.T.	U.T.				
		h m	h m	°	°		
18	June 9	11 55		− 7	W. 93		* 90″
19	15	15 19		+14	W. 29	1 *d*	
20	18	17 20	18 00	+23	W. 67	1	
21	20	10 50	11 10	+27	W. 90		* 40″
22	24	17 06	18 00	−19	E. 25	1 *d*	
23	25	**9 26**	9 38	−10	E. 5	1	
24	July 1	**16 54**	17 20	−13	W. 23	1 *d*	
25	21	**17 55**	18 11	+ 9	E. 42	1	
26	26	**14 00**	14 15	−18	W. 41	1	
27	28	**17 05**	17 20	−12	E. 40	1	
28	Aug. 10	**13 30**	13 45	−12	W. 13	1	
29	10	**17 45**		+ 6	E. 26	1	
30	10	**17 30**		− 6	E. 90		* 50″
31	12	7 15		−14	E. 58	1	
32	12	10 30		−12	W. 26	1	
33	15	**17 20**		− 9	W. 67	1	
34	15	17 25		−14	W. 90		* 95″
35	16	17 00	17 30	+ 8	E. 57	1 *d*	
36	17	**9 47**	10 30	−11	E. 74	1 *d*	
37	17	9 54	10 06	−13	E. 83		* 75″
38	17	10 08	10 27	− 2	W. 70	1	
39	18	9 24	9 30	+ 8	E. 31	1	
40	18	16 56	17 35	−11	W. 90		* 60″
41	27	13 56		−10	W. 7	1	
42	27	**17 15**		−15	W. 59	1	
43	29	15 33		− 6	E. 37	1	
44	29	**17 00**	17 32	+12	E. 80	2 *d*	* 96″
45	30	**16 31**	16 50	+15	E. 33	1	
46	31	**16 50**		+ 6	W. 64	1	
47	31	**16 53**	17 09	− 5	E. 6	1 *d*	
48	31	**17 09**	17 20	− 3	E. 90		* 35″
49	31	**17 17**	17 30	− 5	E. 12	1	
50	Sept. 1	11 40	12 03	− 6	0	1 *d*	
51	2	16 35	17 00	− 5	W. 19	1 *d*	
52	2	16 50	17 36	+ 3	W. 90		* 40″
53	4	**16 48**		− 9	W. 44	1 *d*	
54	6	16 05	16 15	− 8	W. 77	1	
55	7	**16 50**	17 00	− 9	W. 38	1	
56	7	**16 50**		0	W. 90		* 86″
57	Oct. 9	13 55		+18	E. 47	1	
58	Nov. 10	13 21	13 52	+10	W. 81	1 *d*	
59	14	**14 34**	14 56	−13	E. 27	2 *d*	
60	27	**11 50**		+13	W. 16	1 *d*	
61	Dec. 8	11 58	12 12	+18	E. 36	2	
62	17	**13 30**	13 40	+ 1	W. 90		* 70″

Notes

3. Hydrogen of great brilliance obscuring some of the umbræ of the spot-group.
5. Arch prominence which rose 115″ to 211″ in the interval.
44. Base visible as bright eruption on the disk.
56. Quasi-eruptive prominence of great brilliance: length 120,000 km. at angle 60° to solar radius. Max. R.V. −195 km./sec.

IONOSPHERIC MEASUREMENTS MADE DURING THE TOTAL SOLAR ECLIPSE OF 1940 OCTOBER 1

A. J. Higgs

(Communicated by the Director, Commonwealth Solar Observatory)

(Received 1942 January 19)

1. *Introduction.*—Radio measurements made during solar eclipses as early as 1925 and 1927 had established that appreciable effects were produced within the regions responsible for long-distance radio transmission. A suitable technique for determining the changes produced within the ionosphere—the Breit and Tuve pulse or echo-sounding method—was not available, however, until the total solar eclipse of 1932 August 31. In that year extensive observations made in America established beyond doubt that solar ultra-violet radiation rather than neutral corpuscles emitted from the Sun were at least mainly responsible for the production of the lower ionospheric layers—the E and F_1 regions. There was no positive evidence that this eclipse produced any changes in the ionisation of the F_2 region, the upper and generally most important region of the ionosphere.

In an attempt to throw more light on the difficult problem of the F_2 ionisation further measurements were made at subsequent eclipses in 1935, 1936, 1937, and at the partial eclipse of 1940 April 7. Results were, however, inconclusive, and it was still uncertain whether solar ultra-violet radiation or corpuscles, or both, were active in its formation. The unravelling of eclipse effects in the F_2 region is, however, by no means easy. Large and irregular fluctuations in ionisation density are likely to occur at any time, so that the data collected on surrounding days provide no satisfactory control.

Further and conclusive evidence was obtained during these eclipses in favour of the ultra-violet origin of regions E and F_1, and the observations showed that the ionisation produced was closely in equilibrium with the source of ionisation. Support was thus lent to the rather high value for α, the electron-positive ion recombination coefficient, which had been derived from the diurnal variations of the electron density, a value which exceeded the then indicated theoretical value by a factor of 10^2.

The ionisation curves obtained were not sufficiently detailed to reveal what processes were operating in removing electrons. The early simple recombination theory as first put forward by Appleton and Naismith * accounted satisfactorily for daily and seasonal variations in ionisation density. At least for the E and F_1 regions it seemed most unlikely that attachment of electrons to neutral molecules could be negligible. Martyn and Pulley were the first to put forward the suggestion that recombination, attachment to neutral molecules and then subsequent breaking up of the negative ions so produced all occurred together. Massey has shown that this is probably a satisfactory picture of what occurs and that it does account generally for the observed variations, in particular for the apparent behaviour according to a recombination law when, in fact, important attachment and detachment processes are almost certainly occurring. No observations had been able to do more than determine a rough value, for the effective recombination coefficient and the separate reactions involved were well screened.

In spite of the fact that all reasonable opportunities for ionospheric investigations

* *Proc. Roy. Soc.*, A, 150, 685, 1935.

during solar eclipses had been taken, definite evidence on certain questions was still not available. These may be set out as follows:—

(1) Is there a definite ultra-violet effect and/or corpuscular effect within the F_2 region?

(2) Is the ultra-violet radiation which is responsible for the E and F_1 regions emitted uniformly from the Sun's disc?

From the known relationship between radio fade-outs and chromospheric eruptions local and important "hot-spots" are known to exist at certain times; but the regular behaviour of the E region from day to day, in contrast with the much bigger variations for example in the area of bright hydrogen patches visible on the Sun, suggested that these locally enriched areas are of only temporary importance.

(3) Does the Sun show a "darkening to the limb" effect in E region ultra-violet radiation as it does for visible radiation?

(4) Is it possible to obtain evidence that the various processes—recombination, attachment and detachment—are occurring concurrently? If so, values for the coefficients involved would be of considerable interest.

Conditions in South Africa at the total eclipse of 1940 October 1 were particularly favourable for obtaining a definite answer with regard to (1). The corpuscular or particle eclipse (for particles travelling with the expected velocity of 1600 km./sec.) was due to take place at about noon—when the F_2 density is generally near its maximum and the diurnal curve flat. Hence any corpuscular effect should be the more readily detectable. Also, the optical eclipse began about 15 hours local time, when the F_2 density curve is usually still high and the afternoon decrease has not yet begun. Further, if observations could be made at very frequent intervals throughout the eclipse a detailed ionisation curve could be obtained which might be expected to throw light on points (2), (3) and (4).

Considerable experience had been gained at the Observatory in the construction of quick-sweep automatic P'–f (multi-frequency) equipment and it was possible to obtain a complete sounding of the ionosphere in a period as short as two minutes. Observations made at such short intervals throughout an eclipse had never been obtained before.

In view of these considerations, and as it had already been decided to send an astronomical expedition from the Commonwealth Solar Observatory to view the eclipse, it was considered desirable to incorporate radio observation in the observing programme. Owing to limitations imposed by war conditions the expedition was restricted to two members: the astronomical observations were made by Dr. C. W. Allen and the programme of ionospheric measurements was carried out by the writer.

2. *The Equipment Used.*—Apparatus similar to that which has been in regular use at the Commonwealth Solar Observatory for some years was specially constructed for the purpose. It is a pleasure to record the considerable help and co-operation extended by the Radio Research Board in this connection: the Board supplied such of the material and component parts as were not already at hand at the Observatory, including power transformers, valves, cathode ray tubes and a camera for recording. The writer is also grateful to Mr. F. W. Wood of the Radio Research Board for helpful advice and discussion.

The apparatus and circuit arrangements were generally similar to those previously described by H. B. Wood. The essential parts consisted of—

(1) A pulse emitter driven by a synchronous motor, through cams, to cover the required frequency range.

It was considered that an upper limit of 12·5 megacycles per second (mc./s.) would be sufficient to deal with conditions likely to be met with in South Africa. With the two-band type of apparatus used this restricted the lower

frequency limit to 1·6 mc./s. This proved quite satisfactory for our purposes, though the critical frequency just exceeded 12·5 mc./s. on a number of days. Penetration was nearly complete at this frequency, however, and it was usually possible to estimate the critical frequency quite closely. It was arranged that frequency should proceed logarithmically from 1·6 to 12·5 mc./s. and this band could be swept through every two minutes.

Suitable cam switches were provided so that, although this frequency sweep was carried out continuously, power was switched on either continuously or at periodic intervals of 6 to 12 minutes as desired. Operation was entirely automatic, the only attention required being changing of the film-holder at appropriate intervals, usually daily.

As the emitter was of a self-excited type the frequency calibration was dependent on the emitting antenna used. A cage aerial of the Berkner type, mid-frequency 6·5 mc./s., was selected and the whole unit erected and calibrated at the Observatory before leaving Australia. In order to ensure that no difficulty would be experienced in duplicating this aerial at the eclipse site a height of 35 feet was chosen. Although this height was considerably below that for optimum vertical radiation on the lower frequencies it was not intended to transport aerial poles to South Africa, and as conditions and facilities at the eclipse site were not known it was thought wise to select an aerial that would occasion no difficulty in erection on the spot, even if local aid was not forthcoming.

(2) A receiver of the superheterodyne type similarly driven to cover the same range. This was located alongside the transmitter and was fed with signal from two doublet antennæ. These were not critical in any way.

(3) The recording equipment consisted of a light-tight box housing a cathode ray tube (Cossor Type 3232A, with a 5″ screen) and a camera which photographed the echo pattern found on its screen, together with the necessary power supplies and the time sweep and height marking apparatus. The camera was a Zeiss "Ica" using standard 35 mm. film and adapted for continuous film movement. Suitable inspection holes were provided so that the performance of the equipment could be checked at any time, thus obviating the need for a separate monitor.

Height and frequency calibrations were printed on the record automatically. By means of suitable contacts incorporated in the receiver the echo pattern on the cathode ray tube screen was deflected off its slit-mask for a short interval every half megacycle of frequency change. Frequencies could thus be read off at once from the record to 0·1 mc./s. by eye estimation without difficulty.

Height calibrations were supplied from a local 3000-cycle oscillator. The output from this oscillator, after undergoing wave-form deformation to provide a sharply peaked pulse, was supplied to the focussing screen of the cathode ray tube. This had the effect of sharply defocussing the time base at intervals of 50 kilometres of height, and as these defocussed points were stationary on the screen a network of 50 km. height marks was thus "drawn" on the record.

The writer is indebted to Mr. F. W. Wood for a useful suggestion in regard to this height marker. As the constancy of frequency of the local A.C. supply could probably not be relied on to lock this oscillator in a satisfactory manner a stable oscillator was built and so arranged as to operate only during the period that the time sweep was in progress. The constancy of these oscillations was thus not affected by the local supply frequency, yet the oscillator always started up in the same relation to the time sweep—the height marks always being in the same position on the time base, and stationary. The grid

return of this oscillator was taken through a mercury vapour rectifying tube, across which a suitable A.C. mains voltage was impressed. Oscillations only occurred during the positive half of the A.C. wave, and were arranged to start just before the thyratron was tripped.

Eastman Plus X 35 mm. film was used for recording, each 2-minute run requiring about 2 inches of film.

3. *Site and Erection of Apparatus.*—It was known that two other expeditions—from the University of Johannesburg and from Harvard University—intended to make ionospheric observations in South Africa: these parties had selected sites at Middleberg and Queenstown respectively. As the main requisite of the observing site was the availability of a 50-cycle 230-volt A.C. supply the choice of situations was necessarily limited. Victoria West, a small town situated in the Karroo some 400 miles from Cape Town, was selected by the Commonwealth Solar Observatory. This town was situated not far from the centre line of the eclipse track for the ionosphere, and had a period of totality of approximately 4 minutes. The distance from Victoria West to Queenstown was some 250 miles, corresponding to about 16 minutes of longitude. This longitude time difference proved very valuable in positively identifying an ultra-violet eclipse effect in the F_2 region.

The expedition was fortunate in being able to obtain the use of a disused radio station situated some 3 miles from the town of Victoria West. This was already connected with the town's oil-engine-driven A.C. supply and offered an ideal site, with a building already available to house the equipment and to serve as a dark room for the necessary photographic manipulations. Except for rather wide variations in both voltage and frequency of the mains supply—until we provided the engineer with a synchronous clock and arranged with him to make it keep correct time—a satisfactory service free from interruptions was maintained.

Erection of the poles and aerial gear was completed early in August. Regular recording, to serve as control data and for comparison with similar recordings being carried out in Australia, was begun on August 8 and continued until October 8. For the most part, except on the day of the eclipse, when operation was continuous, the transmitter was set for 6-minute operation. Records were measured up roughly on the spot and the results sent back to Australia by an independent route. Fortunately no mishap occurred to prevent the safe return to Australia of the equipment and the original records.

4. *Results*—(a) *E Region.*—The general features and behaviour of the E region can be satisfactorily explained on a recombination theory, where the mechanism of the disappearance of electrons is by combination with positive ions

$$\frac{dN_e}{dt} = I - \alpha N_e^2, \qquad (1)$$

where N_e is the electron concentration, I the rate of production of electrons, and α the recombination coefficient. From consideration of the daytime variation of N_e a value of about 10^{-8} or higher is indicated for α.

The theoretical value for the electron-positive ion recombination coefficient is of the order of 10^{-10}, falling far short of the experimental value: previous eclipse observations, which showed that ion density and ion production were in close equilibrium, supported the higher value.

In addition to simple recombination, electrons might be expected to disappear by attachment to neutral molecules. This process, however, could scarcely give rise to the sharp stratification observed for the E region. Martyn and Pulley were the first to point out that almost certainly recombination, attachment to neutral molecules and dissociation of the negative ions so produced occurred together.

When the effects of these several processes are included the electron density still varies according to a recombination law but with an "effective recombination coefficient" considerably greater than 10^{-10}.

If N_e, N^- and N^+ are respectively the electron, negative ion and positive ion concentrations, λ the radio of negative ions to electrons, and assuming the medium remains electrically neutral, we have

$$N^+ = N_e + N^- = N_e(1+\lambda)$$

and

$$\frac{dN^+}{dt} = \frac{dN_e}{dt}(1+\lambda) + N_e\frac{d\lambda}{dt}. \tag{2}$$

But

$$\begin{aligned}\frac{dN^+}{dt} &= q - \alpha_e N_e N^+ - \alpha_i N^- N^+ \\ &= q - N_e^2(1+\lambda)(\alpha_e + \lambda\alpha_i),\end{aligned} \tag{3}$$

where α_e, α_i are the electron and negative ion recombination coefficients respectively, and q the rate of ion production per unit volume.

Combining (2), (3),

$$\frac{dN_e}{dt}(1+\lambda) + N_e\frac{d\lambda}{dt} = q - N_e^2(1+\lambda)(\alpha_e + \lambda\alpha_i).$$

After a little reduction,

$$\frac{dN_e}{dt} = I - \alpha' N_e^2, \tag{4}$$

where

$$\alpha' = \left(\alpha_e + \lambda\alpha_i + \frac{1}{N^+}\frac{d\lambda}{dt}\right)$$

may be regarded as an effective recombination coefficient at any time. Furthermore, it is probable that the ratio of negative ions to electrons is maintained constant throughout the day (and hence α' is constant) by the electron attachment and detachment processes, both of which proceed at a considerably greater rate than electron-positive ion recombination. As the value for λ can be shown to be of the order 10^2 or 10^3, the higher value for $\alpha'(10^{-8})$ can be satisfactorily accounted for. The electron density thus appears to follow a recombination law even though more important processes are actually taking place.

It is possible that around sunrise and sunset photo-dissociation of ions may play a correspondingly more or less important part leading to a reduced or increased value respectively for α'. It is known that the electron density changes close to sunrise and sunset are not satisfactorily accounted for by the simple recombination law with a value of α' applicable to daytime conditions.

In the discussion of the results that follows it has been assumed that the region remained electrically neutral and that λ, and hence α', were constant throughout the eclipse. While the former is probable, it is not unlikely that with the rapid removal and return of the solar ionising radiation the equilibrium between electron attachment and negative ion dissociation processes was sufficiently disturbed to cause an appreciable variation in λ, and hence a variable α', throughout the eclipse.

A copy of the *H* magnetic tracing taken during the eclipse at Van Rhynsdorp, South Africa, and kindly supplied by Dr. Ogg of the Cape Magnetic Observatory, does not show any marked variation during this period, though a disturbance (decreasing *H*) began shortly after last contact. This was probably not an eclipse effect. The question of a possible variation in α', however, will be returned to in a later paper.

October 1 was not ionospherically normal as far as the *E* region was concerned, densities being lower than usual particularly during the morning. There was, fortunately, an almost complete absence of abnormal *E* reflections during the afternoon, so that the *E* penetrations are generally very well defined.

Densities were calculated from the usual relation * $N_e = 1{\cdot}24 \times 10^4 f_c^2$ where f_c is the ordinary ray critical frequency in megacycles per second. The extraordinary ray was clearly visible at various times during the eclipse.

Fig. 1 shows the course of the ionisation density for the *E* region at Victoria West for October 1, the control curve being taken from the mean of three days each side of

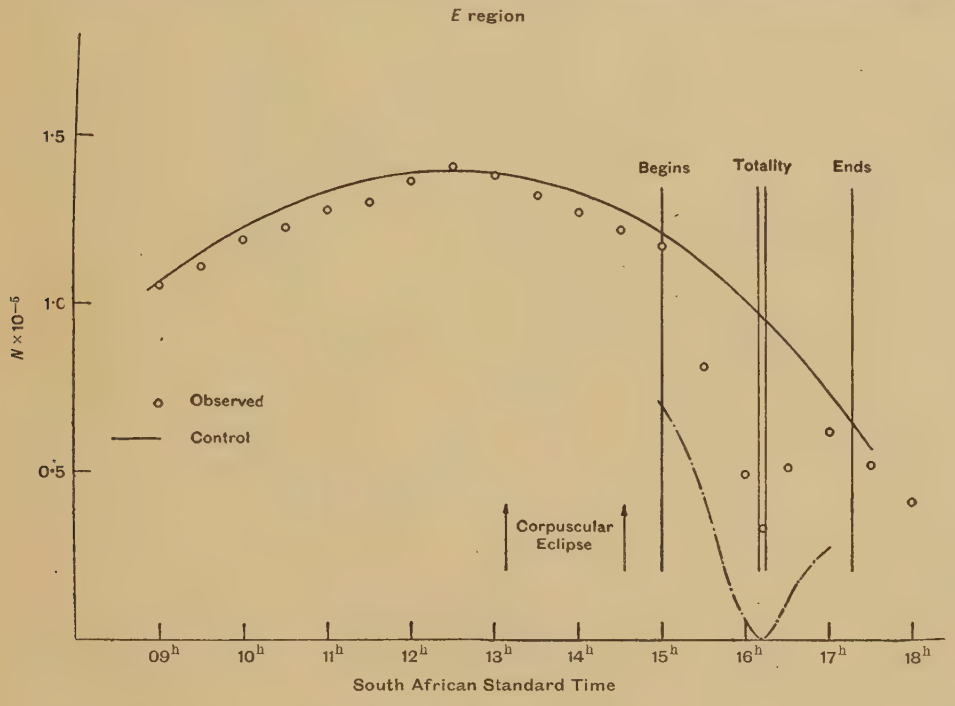

Fig. 1.

the eclipse day. In this figure the solar "ionising factor," *i.e.* the proportion of the Sun's disc exposed, is also shown (vertically displaced in the figure).

It is at once obvious that the ionisation is closely in equilibrium with the source of ionisation. The curve, however, is by no means regular: there are a number of changes in slope and the rise from minimum is very steep. This sudden increase is in the wrong direction to be accounted for by any darkening to the limb effects, and it appeared at once that this effect, if present, was certainly masked by other effects. This rapid increase after emergence could be simply explained if that portion of the limb of the Sun happened to be considerably richer in ionising radiation, and this seemed at least possible because an active sunspot group—which had probably been responsible for a fade-out several days earlier—was situated very close to the limb.

From the observed ionisation curve densities and gradients were taken at 32 points, mostly at 4-minute intervals, but around totality at 2-minute intervals, and a least square solution made for I and α' from the equation

$$\frac{dN_e}{dt} = fI \cos z - \alpha' N_e^2,$$

* Appleton and Naismith, *loc. cit.*

where f is the fraction of the Sun's disc exposed and z is the Sun's zenith distance. This gave

$$\alpha' = 1{\cdot}05 \times 10^{-8} \quad \text{and} \quad I = 249.$$

Fig. 2 shows in more detail changes occurring during the eclipse, together with the deduced ionisation curve for these values of α' and I, attained by substituting in equation

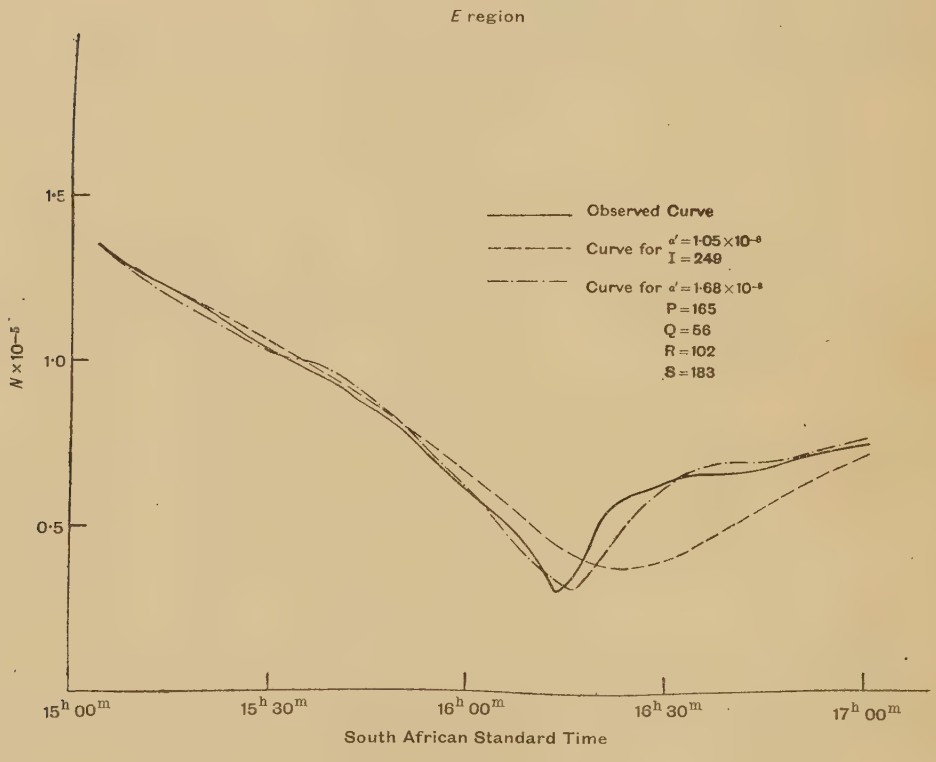

FIG. 2.

(4) step by step. It is clear that, if it be assumed that α' remains constant throughout the eclipse, the assumption that the ionising radiation is proportional to the fraction of the Sun's disc exposed is not adequate to account for the observed changes in E region density.

Spectroheliograms showing calcium flocculi on the Sun's disc for October 1 were kindly supplied by the Director of the Solar Physics Observatory of Kodaikanal, India. These calcium flocculi were grouped into four main regions for purposes of analysis, though, with the exception of the first group—near the limb—each group contained several patches of varying brightness spread over a considerable area.

It was assumed that these groups of flocculi represented areas of specially rich ultra-violet radiation; calling the number of ion pairs produced per second by ionisation from these "hot-spots" P, Q, R and S respectively, the contribution of each was f_1P, f_2Q, etc., where f_1, f_2, etc., were the fraction of these areas operating. The times of eclipse and emergence of these patches were calculated roughly from the known times of contact. The ionisation density is now given:

$$\frac{dN_e}{dt} = (fI + f_1P + f_2Q + f_3R + f_4S)\cos z - \alpha' N_e^2.$$

The best values for the constants I, P, Q, R, S and α' were obtained from a least square solution, using 32 equations over the period $15^h\ 04^m$ to $17^h\ 00^m$. The first result obtained gave I just negative: an unexpected result. Setting $I=0$ gave $P=165$, $Q=56$, $R=102$, $S=183$ and $\alpha'=1{\cdot}68\times10^{-8}$. Fig. 2 also shows the derived ionisation curves using these values. It will be seen that this reproduces reasonably well the actual course of the changes during the eclipse. It was possible to obtain real solutions for the equations by setting successively $R=0$ and $S=0$, but the derived curve did not give such a good fit as the combination plotted.

This result, namely, that the ionisation responsible for the production of region E originates in the bright hydrogen (or calcium) areas on the Sun's disc while a negligible contribution is made from the Sun's disc as a whole, is rather surprising. It should be emphasised, however, that the solution is not unique, and it would be very desirable to repeat the observations at later eclipses when the distribution of bright hydrogen patches would be different. It was difficult to assess accurately the fraction of each area operating at any time, and each contribution of the group did not of course appear in all the equations used in the solution.

It is well known that region E density undergoes a marked variation during the sunspot cycle, as does also the area and brightness of the bright hydrogen or calcium clouds. Specially bright areas as, *e.g.*, during solar eruptions, are also known to exert a marked influence on region E density, though these effects are frequently masked by the fade-out which in a varying degree accompanies such eruptions. An increase in E region density of as much as 30 per cent. has, however, been observed at Mount Stromlo after an eruption. This density increase appears to be exclusive to the E region.

There is thus considerable evidence for the specific controlling effects of bright flocculi on E region density. The generally very regular behaviour of this region, however, which seldom shows much variation in maximum density from day to day, appears at first sight to present some difficulties. Quite considerable changes might be expected, *e.g.* when a bright patch disappears around the receding limb. It may well be that this is the explanation of the changes that are observed from day to day: around September 20, for example, the noon density at Victoria West was $2{\cdot}3\times10^5$ electrons per c.c., while on October 1 it fell to under $2{\cdot}1\times10^5$. This is less than the drop which should have taken place due to the removal of region P (30 per cent.), but it is possible that a further active region had by that time appeared on the advancing limb of the Sun.

A detailed examination of the connection between E region density and size and intensity of bright hydrogen areas will be made in a subsequent paper. For the present one can only state that on 1940 October 1 at least the major part of the ionisation responsible for the production of region E was coming not uniformly from the Sun's disc, but from regions near observed clouds of bright hydrogen or calcium. In this connection, observations made by the Carnegie Institute of Washington at the partial eclipse of the Sun on 1940 April 7 indicated "that the Sun is not giving out the ultra-violet ionising radiation uniformly from all parts of its surface."

An interesting paper has recently been written by Eddington on "Ionisation Equilibrium in a Convective Region." * From this paper it appears possible to account satisfactorily for the increased output from the Sun in the ultra-violet regions, and that actual hot-spots are not only explained, but can be shown very probably to exist.

There is no positive evidence that an appreciable effect was produced within region E by the corpuscular eclipse. The times of the predicted corpuscular eclipse (for 1600 km./sec. particles) for this region have been marked on fig. 1, and it will be seen that there is a small depression of ionisation density approximately coinciding

* *M.N.*, 101, 177, 1941.

with this period. The density was below normal during most of the morning, however, so not too much significance should be attached to this apparent effect.

(b) F_1 *Region.*—The F_1 region was well defined throughout the eclipse. This "layer," however, does not show the relatively simple structure and stable behaviour of the E region, though it is generally considered to show the same marked solar control as does region E. While this is certainly broadly the case, a close examination reveals that more or less regular variations in maximum ionisation density and distribution, with a period of something less than one hour, are continually taking place.

P'–f measurements at intervals of several minutes are required to show up these "pulsations." Such measurements have been carried out at the Commonwealth Solar

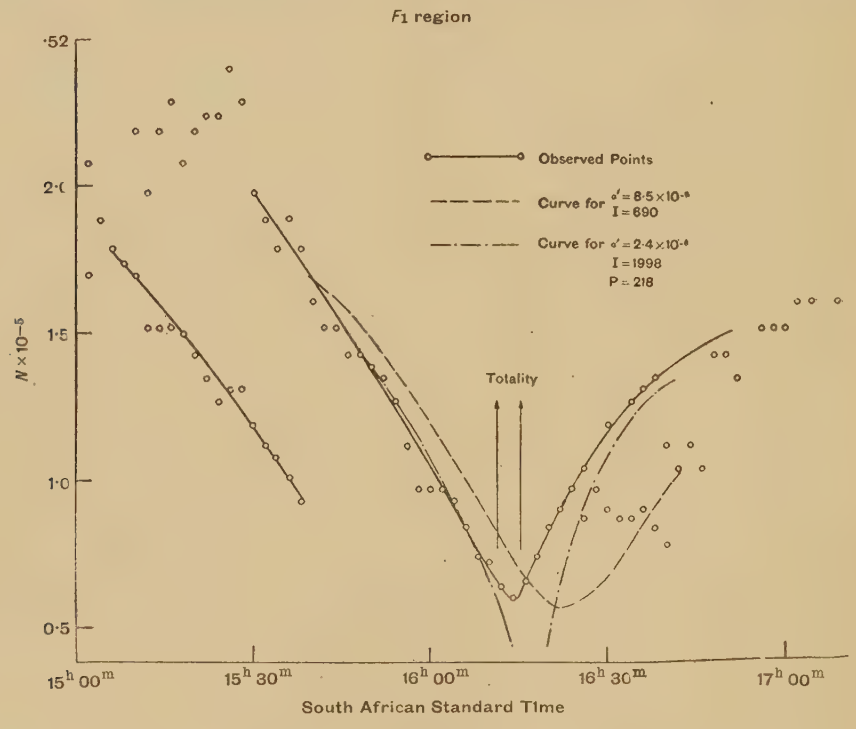

FIG. 3.

Observatory over a number of years and reveal that region F_2 also undergoes similar quasi-periodic variations. These will be discussed in a later paper.

Something of the complex structure of F_1 is revealed in the eclipse observations, plotted in fig. 3. During the early stages, and again after about $16^h\ 30^m$ (South African Standard Time), two ionisation maxima were shown. This is by no means unusual and cannot be attributed necessarily to the eclipse. We shall call that "layer" which persisted throughout the F_1, and that which disappeared at $15^h\ 38^m$ (see fig. 3) the F_{11}.

As the F_1 layer is only clear of "interference" over the period $15^h\ 40^m$ to $16^h\ 40^m$, and since, in any case, the maximum electron density cannot be inferred with anything approaching the accuracy of the E region determinations, it is not worth while making a detailed analysis of the observations. It is clear, however, that the ionisation changes follow the variations in the ionising radiation very closely.

Assuming simple recombination only to take place and that the ionising source is proportional to $f \cos z$ (f being the fraction of the Sun's disc exposed) a least square solution gives $\alpha' = 8{\cdot}5 \times 10^{-9}$ and $I = 690$ electrons per c.c. per second. The curve

derived from these values, depicted in fig. 3, does not follow the observed curve very closely. This is not surprising since, as in the case of the E region, consideration of the decay portion of the curve gives values for α' varying from 2×10^{-9} to 19×10^{-9}, while that portion of the curve after minimum yields negative values for α'.

Fig. 3 also shows a derived curve assuming that area P was making some contribution to the ionisation. This solution results in $\alpha' = 2{\cdot}4 \times 10^{-8}$, $I = 1998$ and $P = 218$, and gives a better fit. Owing to the relatively few observations available it was not worth while introducing the effects of areas Q, R and S. It seems reasonably certain, however, that general radiation from the Sun's disc plays at least a more important part in the production of F_1 ionisation than it does in the case of region E ionisation.

No attempt is made at this stage to account for the stratification and "pulsations" within the F_1 region. It is most likely that the F_{11} curve shown in fig. 3 would still

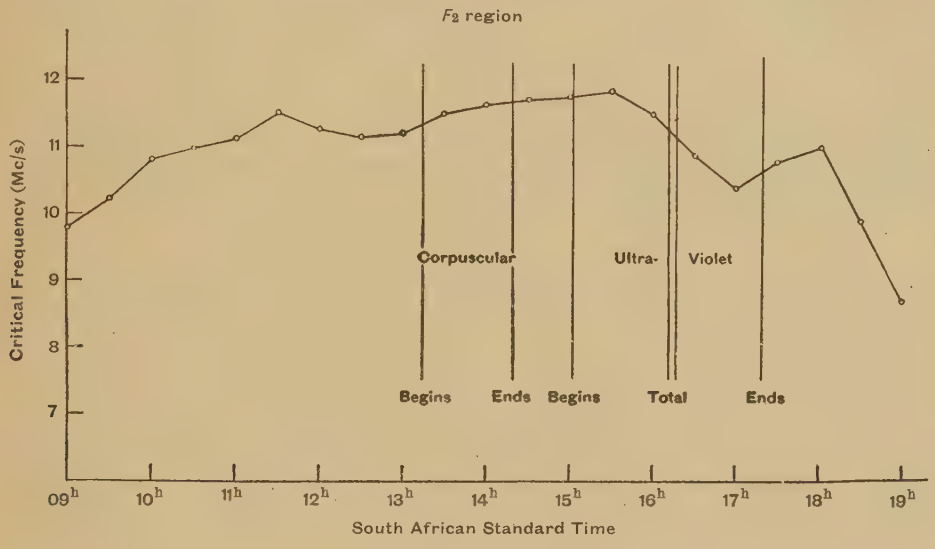

FIG. 4.

have been obtained had there been no eclipse, as quite similar effects were observed fairly regularly throughout the day. An attempt to derive a value for α (for simple recombination), assuming the decay in F_{11} ionisation from $15^h\ 00^m$ to $15^h\ 30^m$ was due to the eclipse, results in negative values being obtained, indicating that, whatever causes were operating, the eclipse effects were not predominant.

(c) F_2 *Region.*—Fig. 4 shows the course of the maximum ionisation density for region F_2 during October 1, the times of corpuscular and ultra-violet eclipses being marked. It is clear that there was no marked corpuscular effect.

Owing to the frequent pulsations in density usually found on practically every day and to the appreciable variations in density and shape of the curve from day to day isolation of any specific ultra-violet effect is rendered difficult. The small "bay" beginning around $15^h\ 30^m$ and reaching a minimum at $16^h\ 45^m$ no more than suggests a possible effect due to the withdrawal of the Sun's ultra-violet light, this dip being quite similar to others noticed on surrounding days.

We have other fairly definite evidence, however, that this does constitute a real eclipse effect. At a conference held at Middleberg, C.P. (South Africa), on 1940 October 5, our results were compared with those obtained by Dr. Halliday at Middleberg, and by Dr. J. A. Pierce of Harvard University expedition at Queenstown. Our results were generally similar to those of Dr. Pierce, namely, that there was a decrease in maximum ionisation density of about 25 per cent., the minimum being reached approximately

30 minutes after totality at both places. The other features of our diurnal curves were similar, relative to local time—which differed by about 16 minutes—whereas the suspected eclipse effects were simultaneous in eclipse time. The density decrease to a minimum, lagging 30 minutes behind totality, was thus very probably a true ultra-violet effect.

Whether the F_2 region has its origin in two separate absorption processes, or whether both F_1 and F_2 arise from the same absorption, F_1 being near the level of maximum electron production and F_2 much above it, as has been suggested, will not be discussed here.

If electron disappearance be by simple recombination, *i.e.*

$$\frac{dN_e}{dt} = fI \cos z - \alpha N_e^2,$$

the value of α derived from the decay portion of the F_2 curve at various points is about 4×10^{-11}. This is of the same order but somewhat smaller than approximate summer daytime values (8×10^{-11}) determined by Appleton.*

Acknowledgments.—The Commonwealth Solar Observatory received a grant from the Joint Permanent Eclipse Committee of the Royal Society and the Royal Astronomical Society. The expedition was financed from this source and from funds made available by the Commonwealth of Australia for the purpose.

Summary

The paper gives a description, with some discussion, of the ionospheric results obtained during the eclipse with automatic P'–f equipment operated at Victoria West, South Africa.

The observations show that—

1. The E region, qualitatively, behaved as expected. Consideration of the ionisation curve shows that the radiation responsible for the production of region E was *not* being emitted uniformly from the Sun's disc, but was coming at least mainly from regions near patches of bright hydrogen.

2. The F_1 region showed, roughly, the expected results, but this region is more complex than is generally supposed.

3. There *was* an ultra-violet effect produced in region F_2, but no corpuscular effect. The density fell by about 25 per cent. to a minimum value about 30 minutes after totality.

Commonwealth Solar Observatory,
Canberra :
1941 *October* 22.

* *Proc. Roy. Soc.*, A, **162**, 451, 1937.

PROFILES OF HYDROGEN LINES IN TWO CLASS B STARS

A. Vibert Douglas, M.B.E., and D. C. West

(Received 1942 February 24)

1. In an investigation by S. Verweij * the profiles of the first four members of the Balmer series were calculated for various values of temperature from 5600° to 18,600° and for seven values of gravity from log $g=1$ to log $g=7$. The influence of Stark effect in broadening the lines is taken into account by making various assumptions and computing the diffusion coefficients at the different pressures corresponding to values of optical depth from $\tau=0$ to $\tau=1$.

The observational data, which must form the ultimate test of the validity of the theoretical profiles, are not very numerous and exhibit rather marked contradictions which go to show how large are the uncertainties introduced by the method of calibration of a spectrum and the construction of the intensity profile from the microphotometer trace. Chances of error occur (1) in drawing the line which best represents the continuous background adjacent to the absorption line under consideration, (2) in the reduction data for the wedge or other intensity exposures and the application of these to any given trace, (3) in the determination of dispersion on the microphotometer trace which cannot always be relied upon to be a constant multiple of the dispersion on the original spectrogram. The difficulty in (1) is notorious and obviously affects the determination of the total spread of the wings, the central absorption of the line and the equivalent width or total absorption of the line. Both central and total absorption are affected by (2); and the error in (3) being cumulative may become quite considerable at a distance of 10 A. to 20 A. from the centre of line, thus introducing a large error into the computation of total absorption as well as into the estimate of line width. All these factors, and differences arising from lack of uniformity in photographic density on different spectrograms of the same star, may lead to quite large discrepancies in the resulting profiles. In view of this it seemed advisable to make a complete examination of as many Balmer lines as possible on the spectrograms of two Class B stars taken by Professor J. S. Foster, F.R.S., and one of the writers in 1932 at the Dominion Astrophysical Observatory in Victoria, B.C.

The material forming the basis of this paper comprises seven 3-prism spectrograms of γ Pegasi and one 1-prism and four 3-prism spectrograms of ι Herculis.

88	γ Peg	B2	$2^m.9$	H.D. 886
85	ι Her	B3	$3^m.8$	H.D. 160762

Microphotometer traces were made from these and intensity profiles constructed from the wedge calibration on each plate by means of the reduction data of Dr. C. S. Beals.†

2. *Half-widths.*—The profiles given in fig. 1 are plotted with the ordinate representing *intensity transmitted*, the continuous background being 1. The profiles from the 3-prism spectrograms of ι Her and γ Peg were reduced to a mean curve for each line.

In fig. 2 the theoretical profiles of Verweij are shown as dotted lines for $H\beta$, $H\gamma$, $H\delta$ for a star of temperature 16,800° with two values assumed for gravity, log $g=4.0$ and log $g=4.4$. His calculations do not provide the data for the residual intensities of the central cores of these lines in the case of the hotter stars. The full lines represent the

* Verweij, *Pub. Ast. Inst. Amsterdam*, 1936.

† Beals, *Pub. D.A.O., Victoria, B.C.*, VI, 9, 98–101, 1934.

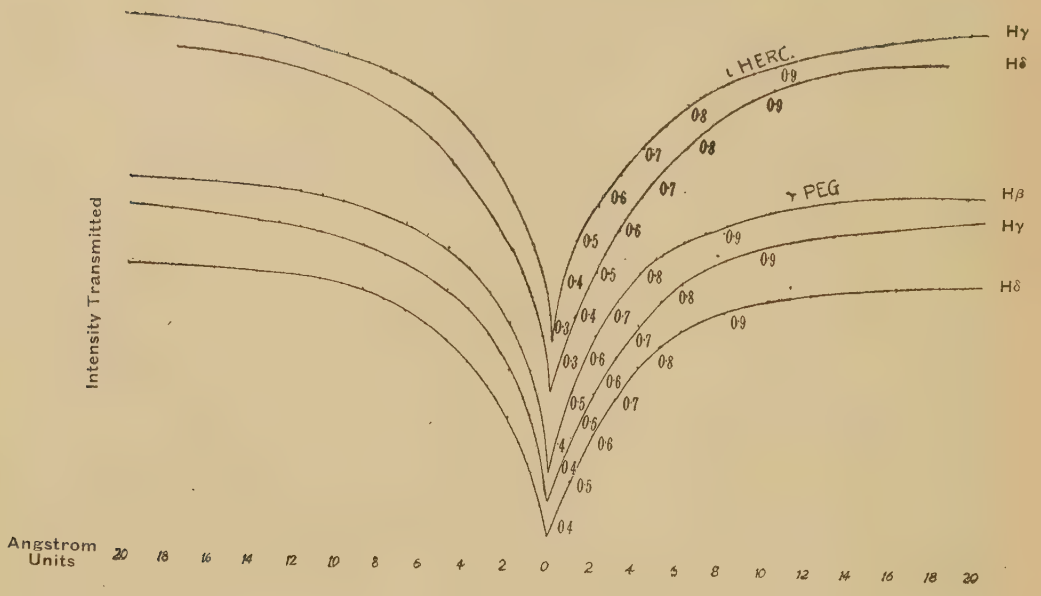
Hγ
Hδ
ι HERC.
γ PEG
Hβ
Hγ
Hδ
Intensity Transmitted
Angstrom Units
20 18 16 14 12 10 8 6 4 2 0 2 4 6 8 10 12 14 16 18 20

FIG. 1.

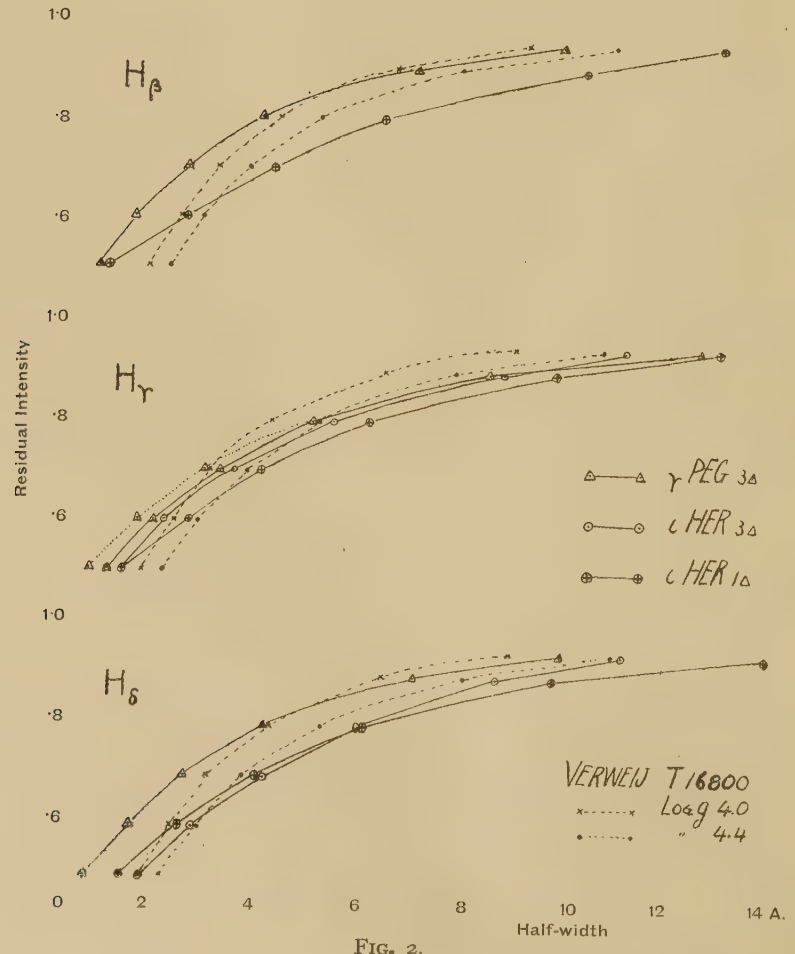
Hβ
Hγ
Hδ
Residual Intensity
γ PEG 3Δ
ι HER 3Δ
ι HER 1Δ
VERWEIJ T16800
Log g 4.0
" 4.4
Half-width
14 A.

FIG. 2.

actual profiles for γ Peg and ι Her over the same range of residual intensity $r = 0{\cdot}5$ to $r = 0{\cdot}95$.

Considering first $H\beta$, it is seen that for $T = 16{,}800°$, $\log g = 4{\cdot}2$, the profile of γ Peg fits the Verweij values well at $r = 0{\cdot}9$ and $0{\cdot}95$, but that the inner portion of the line is much less wide than theoretically expected unless the temperature be assumed higher or gravity very much less. For ι Her the discrepancy with theoretical profiles is very marked both at the core and at the extreme wing. γ Peg being a B2 star and ι Her B3, the hydrogen lines may be expected to be stronger in the latter than is actually the case.

In comparing the actual with the theoretical values for $H\gamma$ separate curves are shown for 1-prism and 3-prism spectra of ι Her, and in the case of γ Peg a dotted profile is added of the violet wing only, since the average wing is influenced by the heavy absorption of the red wing. C. T. Elvey has referred to this excess of absorption in the red wing of $H\gamma$ *, and as exact correction cannot be made for this, both the mean and violet wings are drawn. It is seen, however, that at ± 5 A. the wings become symmetrical. Here again the Verweij values give excessive widths near the line centre ($\pm 1{\cdot}5$ A.) and undervalue the amount of absorption in the outer wings.

The comparison between observation and theory in the case of $H\delta$ is almost exactly the same as in $H\beta$.

The effect of increasing temperature upon the Verweij profiles is to shift the curve bodily towards the line centre and *vice versa*. But since the central portion of a line is produced by absorption taking place at lesser optical depths than that producing the extreme wings, it is obviously impossible to fit a Verweij profile to the observed ones by adjusting temperature alone. His profiles are sensitive to change in gravity, and in order to bring observation and theory into line it would seem to be necessary to postulate increasing values of $\log g$ with increasing values of τ. However, there can be but little modification allowed from this source, and hence the discrepancy between theory and observation remains. It is, however, a discrepancy slightly different from that tentatively suggested by D. S. Evans † in the conclusion of his study of hydrogen lines in A0 stars—"This seems to indicate that the Verweij theory gives values of Stark broadening which are too great." In the B stars under consideration the calculated broadening appears to be too great only for the central portion of the lines where the residual intensity is less than 0·5 for ι Her and less than 0·7 for γ Peg.

3. *Total Absorption.*—In Table I the equivalent widths of lines are given measured in terms of total absorption over 1 A. and in italics are the percentages relative to $H\gamma = 100$. The values obtained by C. T. Elvey ‡ and by E. G. Williams § are recorded to the nearest tenth. Accuracy to three significant figures scarcely seems to the present writers to be attainable. The dispersion is roughly indicated at the head of each column by the number of prisms used. In the final column are shown Verweij's computed values for a star having $T = 16{,}800°$ and $\log g = 4{\cdot}4$. The agreement for $H\beta$ in ι Her is good in every case. For $H\gamma$ the agreement is good save only for Williams's result, which appears to be extraordinarily low both for $H\gamma$ and $H\beta$, and indeed as we believe too low also for $H\epsilon$ and $H\zeta$. Our results indicate an increasing sequence from $H\beta$ to $H\epsilon$. A glance at the microphotometer trace given in fig. 3 will show that the $H\epsilon$ value may be an underestimate. The $H\zeta$ value includes the strong helium line λ 3888·6, but on the other hand the continuous background is very probably drawn in too low, thus considerably reducing the total absorption. The overlapping of the wings of adjacent Balmer lines would appear to have set in here, whether or not such overlapping is already effective between $H\epsilon$ and $H\delta$ as suggested by Elvey and Struve.‖

The very low absorptions found by Williams, Elvey and ourselves for γ Peg relative to the Verweij data indicate that this star is considerably hotter than $T = 16{,}800°$.

* Elvey, *Ap. J.*, **68**, 147, 1928.
‡ Elvey, *Ap. J.*, **71**, 191, 1930.
‖ Elvey and Struve, *Ap. J.*, **72**, 285, 1930.
† Evans, *M.N.*, **99**, 17, 1938.
§ Williams, *Ap. J.*, **83**, 271, 1936.

TABLE I

Total Absorption

Unit 1 A.

	ι Her				γ Peg			Theoretical
	A. V. D. & D. C. W. 1Å	D. & D. C. W. 3Å	C. T. E. 3Å	E. G. W. 1Å	D. & W. 3Å	C. T. E. 3Å	E. G. W. 1Å	Verweij $T = 16{,}800°$ $\log g = 4{\cdot}4$
$H\beta$	6·4 *98*	...	6·5 *98*	6·5 *120*	4·6 *77*	3·4 *77*	4·9 *111*	6·6 *98*
$H\gamma$	6·5 *100*	6·1 *100*	6·6 *100*	5·4 *100*	6·0 *100*	4·4 *100*	4·4 *100*	6·7 *100*
$H\delta$	6·8 *105*	6·5 *107*	...	5·6 *104*	4·9 *82*	...	4·6 *104*	6·9 *103*
$H\epsilon$	9·0 *138*	...	...	6·2 *114*	...	...	5·1 *116*	...
$H\zeta$	7·7 *118*	...	...	6·1 *113*	...	...	5·3 *120*	...

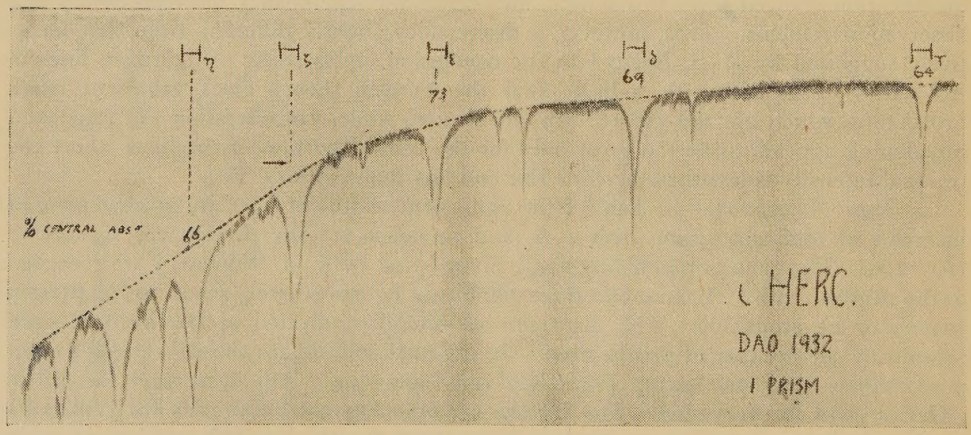

FIG. 3.—*Microphotometer tracing of Balmer lines in ι Herc.*

Plotting Verweij's total absorption against temperature for $\log g = 4{\cdot}4$ as in his Table XV, and making a risky extrapolation, the temperature corresponding to our values of total absorption for $H\beta$, $H\gamma$, $H\delta$ is from 19,000° to 21,000°, the lower value corresponding to our relatively high $H\gamma$ absorption.

It is to be noted that while our values for $H\beta$ and $H\gamma$ in the γ Peg spectrum are 36 per cent. higher than Elvey's, the ratio of the two lines is the same, namely 77 per cent. The low value of $H\delta$, which we find to be only 82 per cent. of $H\gamma$, is interesting. Verweij finds that for solar-type stars the absorption decreases from $H\alpha$ to $H\delta$, but for stars hotter than 8400° there is an increase over this range. Apparently the rate of increase is greatest at about 10,000°, while for hotter stars the rate of increase falls until

at about 17,000° the four lines are of approximately equal intensity. At temperatures above this there seems to be a falling off of $H\delta$. According to Günther *, stars from B3 to A5 have $H\beta < H\gamma < H\delta$, whereas Bo to B2 stars have $H\beta$ the strongest of the three. We find $H\beta < H\gamma > H\delta$ for this particular B2 star, whereas E. G. Williams's results show $H\beta > H\gamma < H\delta < H\epsilon$ for both ι Her and γ Peg.

4. *Central Absorption.*—The percentage absorption at line centre is given in Table II. Values obtained by C. T. Elvey and by E. G. Williams are given for comparison. In addition Elvey's values for α CMa and J. D. Babbitt's † values for α Lyr are added.

TABLE II

Percentage Absorption at Line Centre

	ι Her				γ Peg			α CMa	α Lyr
	A. V. D. & D. 1Å	C. W. 3Å	C. T. E. 3Å	E. G. W. 1Å	D. & W. 3Å	C. T. E. 3Å	E. G. W. 1Å	C. T. E. 1Å	J. D. B.
$H\beta$	57	...	65	53	67	45	51	68	74
$H\gamma$	64	74	60	61	68	58	56	78	82
$H\delta$	69	78	58	63	62	...	61	82	84
$H\epsilon$	73	...	...	64	...	...	58	88	83
$H\zeta$	67	...	...	64	...	...	56	...	87
$H\eta$	66	...	...	...	...	...	59	...	81

The values which we give for $H\zeta$, $H\eta$, namely 67 and 66 per cent. respectively, are measured relative to an assumed position of the continuous background shown in fig. 3. Obviously these are too low, but perhaps not by more than a very few per cent. If we assume a 73 per cent. central absorption for both $H\zeta$ and $H\eta$ it is possible to calculate back to the position where the continuous background should be drawn in. It is indicated in fig. 3 by arrows, and many investigators would no doubt be content to draw the background lower than this.

5. *Acknowledgment.*—The writers are indebted to Miss D. E. Guignard for considerable assistance in making many of the microphotometer tracings and in the reduction of these to line profiles.

Summary

Theoretical line widths computed by Verweij are compared with profiles of certain Balmer lines in spectra of γ Peg and ι Her. Comparison is likewise made regarding total absorption in five Balmer lines and an estimate of the temperature of γ Peg is indicated. The percentage absorption at line centre is compared with the observations of other investigators.

[It may be pointed out that the hydrogen profiles predicted by Verweij's theory, with which the observations of this paper are compared, are based on Pannekoek's calculated values of the continuous absorption coefficient k (*Pub. Ast. Inst. Amsterdam*, No. 4, 1935). These values have since been subject to revision by Pannekoek himself in an addendum to the paper quoted, and by others.—ED.]

* Günther, *Zs. f. Ap.*, 7, 106, 1933.

† Babbitt, *Can. Journal Research*, A, 15, 161–180, 1937.